THE USE OF FERTILIZERS

THE USE OF FERTILIZERS

A GUIDE TO
THE MANURING OF CROPS IN
GREAT BRITAIN

BY

A. S. BARKER
B.Sc., N.D.A. (Hons.)

WITH FOREWORD BY
Professor J. A. SCOTT WATSON

LONDON
OXFORD UNIVERSITY PRESS
HUMPHREY MILFORD
1935

OXFORD
UNIVERSITY PRESS
AMEN HOUSE, E.C. 4
London Edinburgh Glasgow
New York Toronto Melbourne
Capetown Bombay Calcutta
Madras Shanghai
HUMPHREY MILFORD
PUBLISHER TO THE
UNIVERSITY

PRINTED IN GREAT BRITAIN AT THE UNIVERSITY PRESS, OXFORD
BY JOHN JOHNSON, PRINTER TO THE UNIVERSITY

FOREWORD

By Professor J. A. SCOTT WATSON

Sibthorpian Professor of Rural Economy in the University of Oxford

Recent years have brought important changes both in the fertilizer industry and in the business of crop production.

On the one hand the manufacturer is now producing, in addition to the old standard chemicals like superphosphate and sulphate of ammonia, a considerable range of new compounds; some of these, like nitrate of potash and the phosphates of ammonia, are much more highly concentrated than the old familiar substances, and for this and other reasons their use is likely to extend. Moreover the large-scale manufacture of nitrogen compounds from the air has created the possibility of an unlimited expansion in the use of nitrogen fertilizers.

The farmer, on his part, is being faced with new problems. The force of economic circumstances has often obliged him to abandon his traditional rotation and to place less reliance, for the fertilizing of his fields, on the dung-cart and the sheep-fold. He is also seeking new sources of income and is turning more to crops that were formerly considered as belonging to the garden rather than to the farm, and of which he lacks experience and knowledge.

There was thus every need for a new treatment of the whole subject, taking account of the new circumstances and making available to the farmer and the farm student the new knowledge. This need is admirably supplied by Mr. Barker's book.

J. A. S. W.

PREFACE

Agriculturists may feel that an addition to the numerous books dealing with fertilizers requires some vindication. This book is not intended as a contribution to the purely technical literature, of which there is a sustained and abundant output. Such publications, however, are for the most part devoted primarily to what may be termed fundamental and scientific knowledge; investigation, experimentation, and the facts thereby obtained are given detailed consideration rather than the commercial application of the accumulated information. While the manuring of crops must be governed by the available scientific knowledge, this is often scanty and indeed for many crops there is practically no information established by scientific methods. The object of the following pages is to consider our technical knowledge of fertilizers in its economic and practical implications and in the light of the practice of farmers and growers where data established by experiment are not available. From my experience of the fertilizer trade I believe that such a survey requires no apology. In brief, this book is primarily intended for farmers, fertilizer sellers, and agricultural students, i.e. those chiefly interested in the commercial aspects of the use of fertilizers.

A. S. BARKER.

January 1935

ACKNOWLEDGEMENT

To my friends and colleagues, Dr. E. H. Tripp and Mr. L. J. D. Mackie, I am indebted for much helpful criticism, and I must record my appreciation of their kindly interest. Although references have been largely excluded, I have naturally drawn widely upon published material, and I am equally under obligation to many colleagues, farmers, growers, and merchants for their personal experiences in the use of fertilizers.

A. S. B.

January 1935

CONTENTS

CHAPTER I

THE FEEDING OF PLANTS

No long agricultural experience is required to appreciate that the vast majority of farmers in this country devote more thought and attention to the feeding of live stock than to the feeding of crops. While superficially there may appear to be some justification for this general attitude, a little reflection will demonstrate that crops are fundamentally the more dependent upon man's attention.

The farmer looks upon his live stock as individuals, and deficiencies in an animal's diet are more obvious and appear to be of greater importance in terms of the relatively costly individual animal than in those of the thousands of plants in a single field crop. But the animal, given freedom of movement, is able largely to surmount defects in the food-supply, whereas the plant can only suffer from or succumb to them. Moreover, evolution has resulted in the animal being still less dependent than the plant on its environment, through the provision in the early stages of development of food and warmth from the mother and the possession of very efficient machinery whereby the food is reduced to a condition suitable for absorption into the animal body. The plant has none of these advantages apart from a store of food in the seed; it has no protection in the early stages from the vagaries of climatic and soil conditions, it is subject to fiercer competition, it has extremely restricted powers of movement in search of food, and possesses little or no means of rendering the nutrients in the food material into a suitable condition for absorption. In short, the plant is much more helpless than the animal in regard to its nutrition, and as a general principle it would seem incumbent on the farmer to give at least the same study to the feeding of his crops as he accords to the rationing of his live stock.

Since the plant is able to exercise so little control over its environment and food-supply its needs are likely to be less complex than those of the animal. The plant, we may say, has the lower standard of life and it feeds on the simplest of materials, but fundamentally both animals and plants require water, food,

and oxygen for breathing; it is, however, more difficult to secure the optimum requirements of the plant for these materials. This is the problem that is at once the reason for, and is solved more or less successfully by, the various soil-cultivation operations—draining, irrigating, ploughing, harrowing, rolling, hoeing, liming, manuring, &c.

It will be appreciated that manuring is therefore only one of the ways by which the farmer can influence the food-supply of his crops. Manuring should be considered only in conjunction with the other soil manipulations and in relation to those other items in crop production such as climate, soil type, crop variety and purpose, general economic conditions, &c., some of which are beyond the farmer's control. Since the manure is generally given to a crop in one or two applications—in marked contrast to the daily feeding of the animal where the ration can be rapidly and frequently adjusted—unsuitable manuring can rarely be rectified, and if the crop is to meet the farmer's requirements it would appear that he must exercise considerable knowledge and judgement before deciding upon his scheme of manuring. In point of fact, however, very elaborate forethought is neither necessary nor justifiable, as will be explained in the succeeding chapters. None the less the farmer, and incidentally the agricultural merchant also, should understand why such elaboration is undesirable so that he may feel justified in the simplicity of manuring, though he will still be required to apply a broad discretion in his choice of fertilizers and in the manner of their application.

The Foods of Plants.

For a fuller account of the materials absorbed by plants and their functions in the plant's economy, the reader must be referred to a botanical text-book, since a summary is all that is deemed necessary for our purpose.

Among the large list of chemical elements a comparatively restricted number is required by the plant. Those which are normally found in plants are:

*carbon
*oxygen
*hydrogen

*nitrogen
*phosphorus
*potassium
*calcium } supplied in manures.
*magnesium
sodium
*iron
*sulphur
silicon
aluminium
chlorine.

Note:—The elements marked with an * are usually regarded as indispensable—plants have been grown without the aid of the other substances.

In addition to the above list other elements are often taken in by plants in very small quantities, and among these are manganese, boron, fluorine, iodine, copper, arsenic, &c. Comparatively little is known about the effects of these rarer elements, although some of them, such as manganese and boron, have been shown to have a stimulating action on some plants under certain circumstances.

Fortunately, however, in agricultural practice in Great Britain the problem of plant nutrition is narrowed down to a consideration of the supply of nitrogen, phosphorus, potassium and calcium compounds, in addition to water and oxygen. Generally speaking the other plant-food materials are present in sufficient amounts in soils to enable the maximum crop to be obtained when the deficiencies of the last-mentioned substances have been made good to the extent that is economically practicable.

Since oxygen and water are more or less abundant everywhere for crops in this country they have not become articles of commerce, but in order to supply them, or at least to regulate the supply to his crops, the farmer has to expend money in soil cultivation. In fact his expenditure for this purpose is generally greater than that devoted to the purchase of nitrogen, phosphorus, potash, and lime, and rightly so, since the supplies of water and oxygen in the soil have generally a larger influence on the crop than the other substances. The means of regulating

the water and oxygen in the soil are largely outside the scope of our present theme, but the mechanism of control may be summed up in the words 'good cultivation', and calls for all the farmer's skill and his accumulated experience of the particular soil he is farming.

Circumstances influencing the Utilization of the Soil Food-supply.

The amounts of water, oxygen, and food materials in the soil which are available to the plant depend upon the temperature, texture, and composition of the soil; water-supply, drainage and evaporation; cultivation, the nature and activity of the soil bacteria, &c., the species of plant, and anything which influences the physical, chemical, and biological changes that are in continuous operation in the soil. These are the factors that determine soil fertility and the need for, and the nature of, fertilizer application.

It is impossible to gauge the value of the individual influences of these different items on the fertility of any particular soil; all the agriculturist can do in the present state of our knowledge, and this will unquestionably hold true for many years to come, is to compare their combined effect as demonstrated by the yield and quality of his crops with those of crops obtained in other circumstances, i.e. from a different combination of the soil-fertility factors. Comparisons of this nature have been made ever since man began to till the soil, and the conclusions drawn therefrom have been put to practical test by measures designed to modify one or more of the soil-fertility agents in the direction which such observations indicated to be desirable. A wealth of knowledge of the effects of the various factors has been thus accumulated, and, although such knowledge often lacks scientific precision, it seldom leaves doubt as to how any soil may be improved, though there may be less certainty as to which of the various factors are in greatest need of amelioration. Moreover, we are usually unable to forecast accurately the amount of the increased yield and consequently to determine if the particular measure of soil improvement will be economically justified. Before passing to the detailed consideration of the principles of manuring, however, it is desirable to review briefly the general effects of the more important of the items which govern soil

fertility, but for a more fundamental and detailed account of them the reader is referred to a text-book on soil.[1]

Soil Texture and Composition.

Farmers classify soils on the basis of their texture into clays, silts, loams, sands, peats, and chalks. The texture is the resultant of the action of climate and vegetation on the particular parent material, or rocks, from which the soil is derived. There is patently no clear division between one group and another, but all cultivated types contain a proportion of clay, and this material is to be regarded as the 'active' portion of the soil, the part chiefly involved in the chemical changes which occur. For a simple working understanding of the chemical properties of clay it may be regarded as a fluctuating association of an acid portion (containing chiefly silica and alumina) and a base or alkaline portion (containing varying amounts of hydrogen, calcium, magnesium, potassium, and sodium). In every soil the proportions of the various components of the clay are subject to continuous variation. So far as the farmer is concerned it is the relative amounts of the different materials in the second group, the bases, which are of most obvious importance. The bases are 'exchangeable' with each other and the addition of any chemical salt to the soil affects the amounts and the proportions of the different bases in the clay. Thus in most cultivated soils calcium is the base present in largest amounts in the clay. If, however, the soil be treated with a sodium compound, e.g. very heavy applications (beyond the bounds of common practice) of sodium chloride (common salt) or sodium nitrate, some or most of the calcium in the clay is 'exchanged' for the added sodium and a clay of different character results. The sodium clay holds water more tenaciously than the calcium clay and is much more difficult to cultivate; it is stickier when wet and harder when dry. In districts of heavy rainfall and loss of water through drainage, the calcium in the clay may be largely replaced by hydrogen from the water, forming the type of clay called an 'acid clay'. In this case some of the base portion of the clay, i.e. calcium, has been removed and has not been replaced or exchanged by another base material, hence the

[1] For this purpose see *The Soil*, by Hall, *Soil Conditions and Plant Growth*, by Russell, or *The Scientific Study of the Soil*, by Comber.

proportion of the acid part of the clay has been increased. This will be further considered in the later section dealing with lime.

Clay Soils.

From the foregoing it will be seen that clay soils, in which the proportion of clay is so great as to dominate the other soil materials, are likely to be most retentive of substances applied to the soil. Not only is the total amount of bases available for 'exchange' greater, but the passage of water is slower through a clay soil, and moisture and nutrients are likely to be retained better than in other soils, except those containing large amounts of organic matter. Moreover, since clay soils have such large 'exchange' and water-holding capacities, there is much less danger of injury from heavy applications of fertilizer than on other soils (again excluding those containing large amounts of organic matter), where concentrations which are toxic, especially to seedlings on light soils, may occur.

The large amount of water usually present in clay soils makes them slow to warm up in spring, so that germination, early growth, and the activity of the soil bacteria are all retarded. On such soils arable crops are generally best manured with nitrate nitrogen and readily available phosphoric acid, provided the soil is not seriously short of lime. Clay soils are notoriously difficult to work, the surface tends to set or 'cap' with evil effects on the young crop, and no manuring—apart from heavy and long-continued additions of organic matter—can compensate for lack of the required soil cultivations, e.g. autumn ploughing, spring harrowing of cereals, and frequent hoeing of root crops. Clay soils are the most costly to cultivate, their texture preventing easy access of air to the roots and easy movement of water. It is, of course, commonly known that the texture of clays may be improved by additions of lime and organic matter. Generally speaking the soils containing high proportions of clay are in grass and only become cultivated during those periods when the growing of most common arable crops is very profitable.

Some clay soils have a sufficient amount of potash available for practically all crops, and may show no response to the additions of potassic fertilizers; this, however, is by no means universal, and often potash has appreciable effects on clay soils,

though its addition is usually of less moment than that of nitrogen, phosphoric acid, or lime.

Crops on clay soils invariably display a marked response to applications of fertilizers containing phosphoric acid, and the farmer may make it a general rule to use a higher proportion of available phosphoric acid on these soils. On 'sour' clay soils basic slag and mineral phosphates may be preferable to fertilizers containing water-soluble phosphoric acid, since the latter under these conditions may be converted to forms which are practically unavailable to plants.

The use of nitrogenous fertilizers probably requires less discretion on clay soils than on most other types. Nitrogen is invariably needed to encourage early growth, and any excess of the crop's immediate needs is better retained in a clay soil than in a light soil. Moreover, nitrogen may be applied to crops on clay soils later in the season than on lighter soils with less likelihood of undesirable effects, and finally the large amounts of potash available in many clays provide a larger 'balance' for nitrogen than is available in other soils.

Silt Soils.

A soil may be described as a silt from two distinct standpoints: that of the practical man usually embraces an alluvium of comparatively recent origin, a soil with 'body' but not always difficult to work. The soil technologist, however, usually reserves the term 'silt soil' to those containing a high proportion of fine soil particles which are not clay and which are less amenable than true clay to improvement in texture. Silts of the latter category are no doubt largely in grass, and in times of poor prices this is undoubtedly the best means of farming them, and at the same time of giving them the best preparation for cultivation when prices may make them profitable to plough. With the object of improving texture, organic matter and lime are generally the basic needs of this type of silt soil.

Loam Soils.

Any good agricultural soil which presents no extreme character in its texture may be placed in this class. Loams are intermediate in type. They provide no special difficulties in working,

are suitable for a very wide range of crops, and are probably the easiest soils to manure. The water and oxygen supplies to the plant roots are naturally well regulated, since loams do not offer the resistance to water movement experienced on heavier soils, while they retain moisture better than the lighter sands and chalks. Moreover, loams are generally better provided than other soil types with available reserves of nitrogen, phosphoric acid, potash, and lime, so that crops are more tolerant of what on other soils would be ill-balanced dressings of fertilizers. At the same time loam soils are the most likely to give economic responses to generous and correct manuring, since the other factors conducive to large crops are usually in fullest operation on these soils. Conversely, if all manuring be discontinued or reduced over a period of years, the crop yields are likely to be maintained best on good loam soils.

Sandy Soils.

Soils in this category are extremely open in texture, providing easy penetration for oxygen but do not retain much water. They are easily worked, invariably early for the district, but in all localities, except those with frequent summer rains, there is considerable danger of a deficiency of the soil moisture. Lack of water is, in fact, usually the chief factor limiting the yield of the crops. On the other hand sandy soils are well aerated and there is rarely any danger of lack of oxygen in the soil. They are the least retentive of all soils, not only in regard to water but also to nitrogen, phosphoric acid, potash, and lime. Sands contain a comparatively small proportion of clay, and in earlier decades when labour was cheap, clay was often applied for improving sandy soils. Although this method of improvement is too expensive to be undertaken in our present economic conditions, the colloidal portion of the soil may be increased by the addition of vegetable matter. The latter on decay in the soil yields humus, which may be regarded as increasing the chemically active portion of the soil and thus providing more scope for the retention of the plant foods applied in fertilizers.

The addition of organic matter, crop residues, green manure crops, farmyard manure, &c., also greatly improves the capacity of the soil to retain moisture. Sandy soils are usually the type chosen for market-gardening since they warm up quickly

and generally maintain a higher soil temperature the year round, and are easily worked. The market-gardener's first requirement is a high soil temperature since his chief aims are to be early in the season and to secure a sustained rapid growth. By the incorporation of large quantities of organic matter he can usually overcome the water-supply difficulties natural to sandy soils. Moreover, by the addition of humus he is enabled to use large quantities of artificial manures which would often be injurious on the original sand, and by these means he can gradually build up a rich, fertile soil.

Since sandy soils naturally possess such a meagre capacity for retaining materials in the 'exchangeable' condition, they are poor when first brought into cultivation and remain 'hungry' until their retaining capacity has been improved by the addition of clay or organic matter. As a general principle sandy soils require manuring for every crop, and smaller residues of plant foods are likely to be retained than on other classes of soil in the same climate. Moreover, on sandy soils a complete or all-round manuring is invariably required, that is to say, all the four plant foods, nitrogen, phosphoric acid, potash, and lime, are needed.

Sandy soils probably call for more care in manuring than soils of any other type. Nitrogen is most easily lost from sands, and no matter what the crop, an addition of nitrogen is almost invariably needed at some stage of growth if the maximum economic yield is to be secured. If, however, too much nitrogen be available to the crop in the early stages of development, the growth induced may be so luxuriant as to use up the water-supplies available in the soil and in the absence of further summer rains the crop may be unable to complete its development satisfactorily. The ears of corn fail to fill and the large foliage of root crops cannot be supported, and wilts. Moreover, sandy soils are notoriously dirty, and unless weeds are kept in check nitrogen also encourages them, with the result that still less moisture is available to the crop.

Phosphoric acid is not generally required to the same extent on sandy soils as on those of closer texture. Phosphates are desirable to encourage early root development since deep root penetration is required. The open soil texture, however, offers no hindrance to root range, and, provided the onset of drought

is not sudden and early, the roots will follow the water down into the soil. Moreover, phosphoric acid tends to promote early maturity and, since this is also a natural feature of sandy soils, phosphatic fertilizers must be used with greater discretion than on other soil types.

Potassic fertilizers occupy a very important sphere in the manuring of sandy soils, since such soils are notably deficient in potash along with other bases. Hence practically all crops on sandy soils respond to applications of potash, and since these soils are of low retentive capacity, potash must be considered almost annually in the manuring of every crop. Potash deficiency tends to induce a lower rate of starch formation and premature ripening in many plants. Since the natural conditions of a sandy soil are conducive to early maturity, the addition of potash is important in counteracting this tendency, and by encouraging a longer growing season, provides a means for increased crop yields. Very frequently, however, the benefits from potash are manifest in the quality rather than the quantity of the crop, and this feature further emphasizes the necessity for relatively frequent applications of potash on sandy soils. While, generally speaking, potash usually shows its most marked effects on sandy soils, it does not follow that heavier applications of potash are justified on sandy soils than on other types. Any potash not required by the crop is more likely to be lost through drainage or leached from the root zone on sandy than on more retentive soils, and other conditions are not generally such as to permit such large crops to be grown on sandy soils as on those of heavier texture. Consequently the farmer should generally use a higher proportion of potash to the other plant foods on sandy soils and give more frequent dressings, but not necessarily a total quantity of potash larger than he would use on other soils capable of yielding bigger crops.

Peat and Fen Soils.

In this class of soils the dominant constituent is organic matter or the semi-decayed remains of plants, and the use of such soils largely turns on the climatic conditions to which they are subject. The mountainous peat areas may be dismissed at once since they support only a poor natural herbage for sparse grazing by sheep, and their improvement by manuring is not

likely to be a question of much practical moment unless unexpected economic changes occur in British agriculture.

The peat soils in cultivation may be divided into two broad classes, one, 'mild' fen soils which have been subjected to the action of water from limestone districts, and, secondly, ordinary fen, peaty soil, 'moss' or 'black land' which is usually acid and very deficient in lime. Such soils are of comparatively recent formation and extend over large areas of low-lying flat country; in order to make them suitable for cultivation, drainage must be thorough. Soils of this class have great water-holding capacity and are situated under conditions where water naturally tends to accumulate and where it is often susceptible to regulation. Fen soils are therefore generally capable of fully meeting the water requirements of all crops, and, with proper attention to drainage, adequate supplies of oxygen may be secured in the soil.

It has already been indicated that one type of fen soil is well supplied with lime, but for the most part peaty soils are in very great need of lime—so much so that lime deficiency is often the chief limiting factor in crop production. The vegetable matter of the soil is continually subject to the action of bacteria which cause the decay of the plant residues with the production of humus and an increase in the active acid portion of the soil. A base is required to neutralize such soil acidity, and although on other soils periodical applications of lime are made, it is obvious that where the soil contains such a high proportion of vegetable matter, liming to wholly correct the acidity is, on economic grounds, entirely out of the question. Consequently the cropping of acid peaty soils is largely confined to crops which are capable of withstanding the very acid conditions; such are potatoes, oats, rye, rye-grass, celery, &c. On many of these soils frequent and relatively light applications of lime are made which enable useful crops of clover and wheat to be grown.

Practically all peaty soils have large reserves of nitrogenous matter, and when well drained and cultivated, sufficient nitrogen is available to supply the needs of very heavy crops. Consequently nitrogen requirements are small on this class of soil, but on the other hand phosphates and potash are in very short supply and the manuring must largely turn on the application of these two plant foods. Moreover, the farmer must be prepared

to consider the use of phosphates and potash on a liberal basis, since well-cultivated fen soils produce large crops because the three factors with the greatest influence on yield—water, oxygen, and nitrogen—are usually in abundant supply. To make the best use of them and to encourage good quality crops, phosphates and potash are necessary in relatively large dressings. Insoluble forms of phosphoric acid generally give better results on acid soils of this type than on any other.

Chalk Soils.

The dominant constituent of soils in this class is obviously chalk, and these soils are usually shallow and overlying the chalk hills. It need scarcely be pointed out that not all soils are chalky even in a limestone or chalk district. Areas are frequently found where the chalk has been removed from the surface soil and where the latter will naturally fall into one of the classes grouped on a purely texture basis—a clay or loam, &c.

Chalk soils are usually shallow, lacking in organic matter and humus, and except in rainy districts they are often subject to drought. They are generally well aerated, but rarely provide sufficient moisture for the heaviest yields.

Like sandy soils, the chalks rapidly dissipate organic matter incorporated into the soil, and when farming was more profitable, sheep-folding was largely resorted to in order to maintain the humus content and fertility of chalk soils. This method has become uneconomical in recent years and crop residues, occasional green manure crops, and artificial fertilizers are likely to replace the expensive sheep-fold to a considerable extent.

Chalk soils are generally characterized as 'hungry', i.e. lacking good reserves of nitrogen, phosphoric acid, and potash, and therefore, like sands, they invariably need frequent 'all-round' manuring. Nitrogen must not be used too lavishly in spring lest the soil moisture-supply be insufficient to carry a heavy crop through the summer. Phosphoric acid, always in soluble form, should be applied for each crop rather than for the rotation. Potash should be given for the majority of crops on chalk soils, but frequently rather than in occasional large dressings.

Since other factors rarely permit the development of very large crops on chalk soils, the manuring should be usually on a medium basis; heavy dressings are likely to be incompletely

used, and the applications should be moderate and frequent rather than on the principle of a good dressing once per rotation.

Water-supply.

The regulation of the moisture-supply is perhaps the most important of all the factors governing soil fertility. Rainfall is the source of soil moisture; drainage, evaporation, and the removal by crops constitute the losses from the soil. The moisture may be derived from direct precipitation or through the movement of water in the soil under the influence of gravity. The effect of the latter will be largely determined by the lie of the land and frequently causes considerable differences in soil moisture in quite small areas of uneven country. Rainfall, on the other hand, is comparatively uniform over large districts, and though naturally of more economic significance than the local movement of water in the soil, the latter is occasionally of more immediate importance to the farmer.

It is obvious that the difference between rainfall and the losses of water through drainage and evaporation from the soil represents the moisture available for crop production, and this margin largely determines the nature of the cropping. Two districts receiving similar rainfalls may be farmed on very different systems merely as a result of the rate of evaporation; a cool, moist atmosphere such as frequently occurs in proximity to the sea will prevent the losses from evaporation which will be experienced in a dry inland situation.

An excess of water in the soil, unless of a very temporary character, may have results equally as harmful on crop growth as those arising from an insufficiency of soil moisture. To secure removal of excessive moisture before it has a seriously harmful effect on vegetation is the object of soil drainage. Its counterpart in the artificial supply of moisture is irrigation, which is rarely practised in the British Isles, apart from sewage farms and water-meadows. The loss of moisture through drainage, and to a smaller degree through evaporation, is to a great extent governed by the nature of the soil. The finer the soil particles the greater is their capacity for retaining moisture, while organic matter also has a high retentivity for moisture.

The moisture-supply may not infrequently be responsible for fluctuations in crop yields from year to year of over 50 per cent.

No method of manuring can compensate for the effects of ill-regulated soil moisture, and the farmer can never hope to be able to control the supply of soil moisture so as to be certain of securing the optimum moisture conditions for field crops until the weather can be accurately forecast for many months ahead.

Where soils are known to suffer through an excessive amount of moisture the only real remedy is drainage, provided that the increased yields or greater range of crops thereby obtainable are likely to justify the expense of draining. Manuring can contribute practically nothing to mitigate the effects of a water-logged soil, though liming will assist through opening up the surface soil on strong land, provided the water can get away from the subsoil. On arable land an impervious layer of soil—a plough-pan—often develops as a result of ploughing and other cultivation operations always moving the same layer of soil while the soil immediately below is pressed by horses' feet and the passage of implements. Such a 'pan' has undesirable effects on the soil moisture-supply to crops in both wet and dry periods. It prevents the seepage of water into the subsoil, thus tending to produce a water-logged soil in which root range is restricted through lack of oxygen. Plants grown under such conditions naturally suffer severely during a period of drought, since their roots have not penetrated to a depth sufficient to enable them to tap the water-supply in the subsoil. The amount of water in the subsoil may also be reduced since the 'pan' greatly impedes percolation and more water is left for evaporation from the surface soil.

While the soil loses water by direct evaporation from the surface layers, there is also a tremendous loss through evaporation from the leaves of plants. The magnitude of this loss is indicated by the fact that from 250 to 500 tons of water may be evaporated by the crop in the production of each ton of dry matter. An average cereal crop will thus dispose of some 600 tons of water per acre, an amount equivalent to 6 in. of rainfall.

Manures can do little to counteract the natural conditions which result in an excessive amount of soil moisture, but organic matter may have a very beneficial influence on soils naturally deficient in moisture. The ploughing-in of farmyard manure,

and more particularly of temporary leys and other crop residues, increases the moisture-holding capacity of the soil. It must, however, be appreciated that such means imply the incorporation of many hundredweights of organic dry matter per acre and that the addition of a few bags of a so-called 'organic compound' can have no direct significant effect on the moisture-holding properties of the soil. It is in fact doubtful if such a manure would have so much effect as a large dressing of some inorganic salts such as kainit or common salt which frequently assist a crop over droughts of short duration, probably through increasing the concentration of the soil solution and thereby reducing the rate of evaporation. Moreover, it must be remembered that the correct use of fertilizers will considerably increase the crops grown, and bigger crops leave bigger residues in the soil which have the same effect on soil moisture as other additions of vegetable matter. The rate of increasing the humus content of the soil by this means alone will naturally largely depend on the crops grown and the rotation followed, but there can be very few soils where it is absolutely necessary to apply farmyard manure or 'organic fertilizers'. This aspect of the matter will be again considered, but meanwhile it must be recognized that fertilizers cannot make good the lack of correct cultural operations for dealing with an excessive or defective supply of soil moisture. Reliance must be placed on drainage, subsoiling, proper methods of cultivating at the appropriate time, and means of increasing the vegetable residues in the soil. When the moisture-supply has been adjusted to the best advantage by these means, then fertilizers may be used liberally to secure a full return, not only on their own cost but also on the outlay for all the other operations. On the other hand, where the conditions regulating soil moisture are not of the best, fertilizer applications should be more frugal since there is less certainty of a full return on them.

Finally, the farmer may take recent weather into consideration to a limited degree when deciding upon the manuring of crops in spring. After a winter in which rainfall has appreciably exceeded the normal, the rate of application of nitrogen may be increased, since the depletion of this substance from arable land during autumn and winter is roughly proportional to the rainfall. Moreover, where weather conditions have prevented the

preparation of a good tilth for the seed-bed, a heavier dressing of fertilizers is justified than where the crop is put in under ideal conditions.

Effects of Organic Matter.

Additions of organic matter to the soil are almost entirely in the form of plant debris, through the ploughing-in of crops, stubbles, or farmyard manure. Such plant residues are decomposed by bacteria in the soil and the rate of decomposition is a rough measure of the fertility of the soil. A rapid rate of decay is an indication of satisfactory aeration of the soil and a suitable soil temperature. The decomposition of vegetable matter produces humus, the acid colloidal material which has effects very similar to those of the acid part of clay.

The addition of large quantities of undecayed vegetable matter containing little nitrogen may result in depression of crop yields. The probable cause is the need for nitrogen by those bacteria responsible for the decomposition, which have otherwise food in plenty and conditions favourable to their rapid development. Under such circumstances the bacteria seize on any available nitrogen in the soil, to the detriment of the growing crop, at least until the early stages of decomposition are completed. Consequently, where large amounts of undecayed organic matter are to be incorporated in the soil, the work should preferably be carried out in early autumn, since soil conditions are then favourable for rapid bacterial action and there is generally a store of nitrogen available, which if unused would only be lost through the winter rains.

It has already been pointed out that the addition of vegetable matter has beneficial effects on the fertility of practically all soils; when unrotted it 'opens up' strong soils, and on the light lands decayed organic matter gives 'body' to the soil and improves the moisture-holding capacity. For these reasons and for those characteristics associated with humus, the amount of organic matter in the soil is one of the most important features in soil cultivation. Recognition of this fact is exemplified in the practices of sheep-folding on arable land, the feeding of bullocks primarily with the object of converting straw into farmyard manure, and in the making of composts. While it cannot be

questioned that farmyard manure is a valuable addition to any soil under arable cultivation, it must be recognized that this method of manuring is usually an extremely costly one, and while all farmers do not make a fetish of the dung-cart, very few pause to consider its cost.

It is important to appreciate that crop residues form the main source of organic matter to soils in this country, and that even where heavy applications of dung are made they do not necessarily have a preponderating influence on the amount of organic matter in the soil. In every ton of farmyard manure applied on to the land the farmer hauls 15 cwt. of water, and a dressing of 12 tons per acre of dung only supplies 3 tons of organic matter, containing about 140 lb. of nitrogen, 60 lb. of phosphoric acid, and 100 lb. of potash. Under most soil conditions the amount of organic matter may be increased rapidly without the use of dung by the ploughing-in of temporary leys, green manure crops, and thick stubbles. For this purpose good crops may be secured through the use of artificial fertilizers alone, and the better the crops the richer will the soil become under a proper system of farming. Under present-day conditions only in very rare circumstances can the making or purchase of farmyard manure be justified merely as a means of maintaining or increasing soil fertility. Precisely the same argument must apply to the purchase of other organic fertilizers with the idea of increasing soil organic matter. While all live stock farmers have manure which must be applied to the land, the cost of its application should always be recognized, and where long hauls are involved it will generally be found most profitable to apply it on fields near the homestead, and to rely on fertilizers in conjunction with a suitable rotation for the cropping of more distant fields.

Apart from organic matter the value of farmyard manure lies in the nitrogen, phosphoric acid, and potash it contains. Investigations have shown that the plant foods in farmyard manure are not nearly so readily available as those in fertilizers, and in fact are usually less than half as effective, weight for weight, as those in artificial fertilizers.

In deciding upon the fertilizers to be applied to any crop, the influence of recent additions of organic matter should be taken into consideration. Since the plant foods in organic materials

usually only become slowly available for the feeding of plants, and since vegetable residues are generally deficient in phosphates in relation to nitrogen and potash, it is invariably necessary to supplement farmyard manure and other organic materials with artificial fertilizers. This aspect of the use of fertilizers will be reviewed in more detail under the manurial recommendations for the individual crops, but broadly speaking the only practical interpretation the farmer is justified in making is to increase the application of a balanced fertilizer dressing where dung or rich organic matter has not been incorporated with the soil since the previous crop.

Where sugar-beet tops are ploughed in they supply a similar quantity of organic matter to well-made farmyard manure. Other crops in the green state are also approximately equivalent in organic matter to farmyard manure weight for weight, but their effect from the fertilizer aspect may differ. Generally speaking, when farmyard manure is applied it is in an advanced stage of decomposition, whereas with green crops the process has not begun. Such crops should therefore be ploughed in some weeks before the following crop is to be sown. While green crops do not in themselves enrich the land in plant foods, excepting of course the legumes which accumulate nitrogen from the air, they are likely to increase the proportion of the plant foods in the soil which is readily available to the succeeding crops. On the other hand, farmyard manure may result in an apparent gain of plant food to the farm through the residues from purchased feeding stuffs. Since, however, of the organic matter removed from the land up to 50 per cent. may be lost during its conversion to farmyard manure, there can be little justification for the process in so far as crop husbandry alone is concerned, except where land must be intensively cropped.

It is generally bad farming practice to feed bullocks unless they leave more than sufficient profit to cover the losses of organic matter, &c., involved in using them to convert crops into farmyard manure. It is foolish for the farmer to be prepared to lose money on his bullocks and to delude himself that the farmyard manure obtained can be set against the loss. The folding of sheep on arable land is identical with bullock-feeding; if a loss is made on the sheep the farmer has an additional loss of organic matter and plant foods. Sheep-folding is only justified

when the profits on the sheep themselves are more than enough to pay for the loss of crop residues which the practice involves.

The most economical method of dealing with crop residues is to arrange for their decomposition in the soil, and only to feed them to live stock when the latter are likely to leave a profit after paying for the extra labour incurred and the loss of organic matter and plant foods.

Where the soil is almost continuously under crop as in some types of intensive cultivation, it may of course be more economical to decompose part of the organic matter before adding it to the soil. Though this method involves larger losses it does not interfere with a rapid sequence of crops. The rotting of vegetable matter is brought about by bacteria and the process is not dependent upon live stock. Given the right conditions, straw and other vegetable products can be converted to a material practically indistinguishable in its effects from farmyard manure. In essence the process is that of the centuries-old practice of making compost heaps, in which nitrogen was supplied in green vegetable matter and urine. The bacteria require moisture, nitrogen in readily available form, and sufficient basic material to prevent the development of too great a degree of acidity before the rotting process has reached the desired stage. Straw, &c., can thus be rotted down to make artificial farmyard manure by the addition of a soluble nitrogenous substance, such as sulphate of ammonia, together with ground limestone and sufficient moisture to keep the mass damp. The decomposition can be allowed to proceed to give 'long' or 'short' manure, as desired. Since fresh green vegetable matter usually contains nitrogen which can easily be utilized by the bacteria, it is only necessary to add limestone to material of this nature. On some farms the compost heap provides a cheaper method of converting organic matter to the state desired before its incorporation with the soil than relying upon livestock to achieve the same ends.

In the cultivation of many crops, especially of green vegetables grown for human consumption, it would perhaps seem that there is a particular virtue in farmyard and other organic manures. This view cannot hold true for all conditions, since satisfactory crops are grown even under market-garden cultivation without the aid of dung or other organics. It is, however,

unquestionable that if reliance be placed on artificial fertilizers alone more skill is required than where organics are employed. These crops undoubtedly thrive best and give the best quality produce when they are grown on a rich soil from which they can be steadily and well fed throughout. The decomposition of the organic matter induces a higher soil temperature and more carbon dioxide, both of which are favourable to plant growth. Heavy and frequent applications of farmyard manure are an obvious means of building up a soil to fulfil these requirements, which also of course include a regular and reliable moisture-supply. Much the same result can be achieved by the use of artificial fertilizers along with other means, such as green manure crops and composts of decayed vegetable materials, of increasing the organic content of the soil. Most vegetable crops can be grown quite satisfactorily after potatoes and sugar-beet, &c., which have been heavily manured with artificials. In some circumstances, however, it may be more economical to purchase dung for maintaining the desirable amount of soil organic matter, since the high costs of market-gardening can sometimes only be met by continuously growing cash crops giving high returns per acre. Furthermore, a medium which will encourage rapid and unchecked root development, especially in the early stages of growth, is greatly desired. This is best provided by organic matter which has not fully rotted, which gives the soil 'fibre' and prevents 'panning-down' of the surface soil, thereby improving aeration and reducing the need for surface cultivations after planting.

The majority of soils under market-garden cultivation usually receive heavy dressings of artificial fertilizers in addition to large amounts of organic materials, and the two counteract each other's dangers. The possible evil effects of large applications of undecayed organic matter have been previously mentioned and the addition of fertilizers assists the bacteria by providing them with foods and thus hastening the decomposition of organic matter and more quickly rendering its substances available to plants. On the other hand, the dangers of poisoning from large dressings of fertilizers on light soils are greatly reduced by the incorporation of organic matter.

All organic manures do not enrich the soil in humus, since the latter is a product of vegetable decomposition, and the

amount in the soil will not be directly increased by addition of animal products, such as blood meal, hoof and horn, guano, fish manure, &c. Such materials should be regarded as supplying plant foods in less quickly available form than inorganic fertilizers, rather than as sources of organic matter having the properties of humus.

CHAPTER II

THE PLANT FOODS SUPPLIED BY FERTILIZERS

THE object of manuring is to remedy deficiencies of plant foods in the soil to the extent necessary to produce the maximum economic crop which the environment and other conditions will allow. The chief factors which combine to form the environment have been reviewed in relation to manuring, with the deliberate omission of special consideration of cultivations. The latter have as their object the amelioration of the soil fertility factors whose influences have been discussed. The various cultivation operations are so numerous, and methods adopted to achieve the same purpose vary so widely from soil to soil and district to district, that anything like a survey of them would be out of place in this book.

Each of the principal soil-fertility factors, i.e. soil texture and composition, water-supply, temperature, organic matter, activities of soil bacteria, &c., may have a profound influence on the plant foods available for crop production. Each of these factors interacts on the others, their separate effects cannot be assessed, and at any given time the state of some may be favourable to crop production while the reverse may hold for others. Moreover, before manuring can be decided in relation to these factors other considerations of equal importance have to be borne in mind, such as crop variety, the purpose for which the crop is to be grown, the previous and the succeeding crops, cleanliness of the land, and, most important of all, the costs of production and the cash return from the crop. It is obvious that the farmer cannot attempt to take into account all the foregoing items before deciding on the type and quantities of fertilizer to apply. Even if the different factors were not in continual fluctuation the farmer cannot know the effects of the three principal considerations, weather, costs, and prices, until the crop is grown, harvested, and sold; hence he will never be in a position to know accurately what form of manuring will pay him best. If anything further were required to emphasize the needlessness and folly of attempting to practise or to recommend fine distinctions and discrimination in crop manuring, it

is provided by the necessity of the farmer ordering his fertilizers before the crop is sown, and before he has much idea of the conditions under which its early development will take place. Obviously there can be no justification for any but wide and liberal interpretations of manurial formulae and recommendations; no one can have any reasonable grounds for haggling over differences of a few pounds per acre of nitrogen, phosphoric acid, or potash.

So far as the practical use of fertilizers is concerned, the chemical and mechanical analyses of soils in this country are of small value. It is, moreover, difficult to find practical justification, except in rare circumstances, for individual farmers to submit their soils for germination or pot tests, ostensibly designed to demonstrate what fertilizer treatment is required. The farmer is often enjoined to put down a simple trial plot of some given fertilizer treatment for his own information, but except where his present methods are patently wrong and demonstration thereof is required, it is very doubtful if such a trial can provide him with much significant knowledge on the majority of soils. With the limitations already described in the application of our knowledge, we possess enough information to recommend fertilizer dressings for nearly all ordinary circumstances sufficiently precise for the farmer's needs. This argument does not imply that the farmer should not endeavour to understand the principles of fertilizer practice and that all he need know and concern himself with are three or four mixtures required for his own farm. Even though his cropping, cultivations, and soil conditions remain relatively constant, economic conditions are always changing and the use of fertilizers may have to be modified accordingly. Nor is it suggested that trial plots of fertilizers on farms are unnecessary, since at the present day no other aspect of technical work in connexion with the use of fertilizers approaches this in importance, but it is the economical rather than the research aspect which requires emphasis. Where problems exist which require investigation the experimental methods necessary for reliable elucidation can be used only by trained investigators.

In recent years great advances have been made in fertilizer manufacturing processes, and many entirely new fertilizers have been made available for farmers. In order to appreciate and

take advantage of the results of this advance in manufacturing technique the farmer and merchant should understand the broad principles of manuring. It is still common practice to speak of manurial dressings in terms of individual fertilizers instead of in terms of nitrogen, phosphoric acid, and potash. There is no more rational basis for this than there is for considering the food requirements of animals in terms of the individual feeding-stuffs rather than in terms of protein, starch equivalent, fibre and mineral matter. There was possibly some excuse for the practice when the farmer's choice was limited to perhaps half a dozen fertilizers, but with the recent expansion in the range of fertilizers supplying one recognized plant food, and with the relatively increasing use of commercially made mixtures and compounds, there is need for a terminology which is simpler, of better value for comparative purposes, and generally more rational. Consequently manurial requirements should be considered in terms of lb. per acre of nitrogen, phosphoric acid, and potash, with provisos where needed as to their form, e.g. ammoniacal, nitrate, or organic nitrogen. To this course there is the purely academical objection that the accepted canons of manuring do not rest upon evidence secured from experiments with the three 'pure' plant foods, since all the so-called 'straight' fertilizers are compounds and mixtures of two or more substances, each of which may affect the food supply of the plant. Sulphate of ammonia, for example, which is the purest 'straight' fertilizer, contains nitrogen in the ammoniacal form and also the sulphate part, which causes increased leaching of calcium and other bases from the soil. The effect of sulphate of ammonia is therefore the resultant of the two effects of the ammonia and sulphate radicles. This argument applies with even greater force to other 'straight' fertilizers; they are mixtures of various compounds, one or more of which contains one of the three recognized plant foods.

Fertilizer experiments have shown that the effect of the nitrogen, phosphoric acid, or potash, as the case may be, is so overwhelmingly greater than the effects of the other substances with which each is mixed or combined in fertilizers, that under practically all circumstances attention need only be given to the amounts and form of nitrogen, phosphoric acid, and potash applied.

Before describing the various fertilizers, we may summarize the functions and effects of plant foods which are supplied in fertilizers.

Nitrogen (N).

Of the farmer's raw materials nitrogen is one of the most important, it is present in all animals and plants, combined with other substances as proteins and allied compounds. The proteins of animals are derived from nitrogenous materials in plants and the latter have built up these products from the plant foods extracted from the soil and air.

Every one is aware that water exists as a vapour in the air and in combination with a wide variety of other substances in the bodies of plants and animals, and that the sea is Nature's water reservoir. Nitrogen may be regarded from the same point of view. The natural reservoir of nitrogen is the atmosphere where nitrogen exists as a gas, and it is present in combination with other substances in the bodies of all living things. It is instructive to consider in outline the various steps in the conversion of the raw material nitrogen into the finished farm products and its subsequent return to the original state. The cycle of changes is as follows:

Nitrogen additions to the soil	—from farmyard manure and other plant and animal residues. From the air through action of bacteria, leguminous plants, and application of fertilizers.
Conversion to plant foods	—Complex nitrogen compounds reduced by bacterial action, &c., in soil to simpler nitrate and ammonium compounds which plants can absorb.
Assimilation by plants	—Nitrate and ammonium compounds extracted from soil are built up in the plant into proteins and similar materials.
Utilization by animals	—The plants are consumed by live stock, the vegetable proteins, &c., converted to animal proteins which are important constituents of meat, milk, wool, eggs, &c.
Break-down of proteins	—The proteins are ultimately broken down into simpler products by animals and/or bacteria, and these break-down products ultimately yield nitrates or ammonium compounds in the soil, or gaseous nitrogen to the atmosphere.

Nitrogen Assimilation by Leguminous Crops.

The members of the leguminous, or pod-bearing, family of plants have the faculty of extracting their requirements of

nitrogen from the air in the soil. This character is really possessed by certain bacteria which live in the roots of leguminous plants, and once the latter are established they rarely respond economically to applications of nitrogen to the soil. In the initial stages of development on poor soils, crops of this family often repay the application of nitrogenous manures.

Clovers, vetches, beans, peas, lucerne, sainfoin, and lupins are all collectors of nitrogen, and while the removal of the crop necessarily involves the removal of large amounts of nitrogen from the land, yet the roots and residual vegetation contain nitrogen which is a clear gain to the soil and may reach 100 lb. of nitrogen per acre per annum, though naturally not all of this may be available to other crops. Consequently legumes are usually employed as soil renovators in addition to their value as human or stock foods. They enrich the soil in organic matter and nitrogen, and a two- or three-year clover ley in a six-year rotation may largely dispense with the need for nitrogenous fertilizers for the cereal crops, especially in times of low agricultural prices.

Of the plant foods supplied in fertilizers, nitrogen has generally greater influence on crop yields than either phosphates, potash, or calcium. The effects of nitrogen in farm practice are generally much more obvious than those of the other plant foods, and in any fertilizer mixture under most circumstances it is nitrogen which has the dominating effect on the amount of crop increase.

The effect of nitrogen is manifest principally in the green foliage of the plant, but since the amount of grain or root is usually closely dependent on the amount of foliage, the yield, so far as fertilizers may influence it, is governed by the nitrogen available to the crop. Nitrogen encourages the plant to make rapid growth, which if uncontrolled may introduce undesirable features such as weakening of the straw of cereals, soft and sappy tissues more prone to fungus diseases and frost damage than tissues of slower development. Abundance of nitrogen produces a rich, dark green colour of foliage, whereas nitrogen deficiency is shown by slow development and backward condition of crops, and pale, yellowish-green foliage. This condition is often seen in a cold spring, especially on heavy soils. Nitrogen in excess tends to encourage the plant to keep growing and thus delays the ripening and maturation of the crop.

The effects of nitrogen are tempered by sufficiencies of other plant foods and good soil conditions. Deficiencies in the other requirements of plants may result in undesirable effects from additions of nitrogen to the soil. In considering any one fertility factor its relation to the others must be kept in mind; a point which emphasizes the advantage of applying complete fertilizers rather than a single plant food or unbalanced manures. Additions of nitrogen to the soil tend to increase the amount of nitrogenous compounds in plants and to depress slightly the proportion of dry matter, but these points are rarely of much practical significance.

The amounts of nitrogen removed from the soil by crops naturally differ widely according to the other circumstances influencing crop yields, but cereals and hay remove about 40 to 60 lb. per acre, root crops half as much again, and forage crops, such as cabbage and kales, double the amount of cereals. Of the nitrogen applied as fertilizer, generally speaking about 50 per cent. is recovered in that part of the crop removed from the land; the balance is lost from the soil chiefly through drainage or is stored in the crop roots and weeds. Nitrogen is more liable than other plant foods to be leached from the soil, the loss largely depending on the chemical form of the nitrogen. Nitrogen may be present in soils or applied to them in three forms: ammoniacal nitrogen, nitrate nitrogen, and organic nitrogen. The first and last forms are not liable to removal by leaching, but nitrate nitrogen on the other hand may be lost through drainage. Of the three types of nitrogen compounds the nitrate is the most readily available and usually acts most rapidly on agricultural crops, ammoniacal nitrogen occupies an intermediate position in this respect, and organic forms of nitrogen are generally the slowest in action. For the most part plants only take up nitrogen in either the nitrate or the ammoniacal form, and consequently organic nitrogenous materials must be decomposed by soil bacteria before they can be utilized by plants. The rapidity and extent to which organic nitrogen feeds the crop is therefore dependent on the soil bacteria and the conditions under which they have to work. Thus organic nitrogen has its greatest value in the production of crops with a long growing period, and which must be kept steadily growing, since the activities of soil bacteria are continuously liberating

available nitrogen from the organic reserves in the soil; several of the market-garden crops thrive best under these conditions and are more easily grown where large reserves of organic nitrogen are present in the soil. Not nearly so good a return of nitrogen can be secured when applied in organic form as is obtained from fertilizers supplying ammoniacal or nitrate nitrogen. On market-garden soils there is undoubtedly a relatively large waste of nitrogen from the organic residues which are continuously undergoing decomposition.

Comparative Value of Nitrate and Ammoniacal Nitrogen.

Nitrate nitrogen is, weight for weight, more costly than ammoniacal nitrogen, and consequently it is desirable to indicate when the nitrate form is worth the extra price. On most farm crops nitrate nitrogen induces a quicker response than ammoniacal nitrogen, and when the crop is flagging from the effects of a cold, late spring, insect attack, or from singling in dry weather, nitrate nitrogen is preferable provided it can be obtained for little more than the cost of ammoniacal nitrogen. On the other hand, where nitrogen is applied at sowing time, and where a steady and more prolonged effect is desired, ammoniacal nitrogen should be chosen. Moreover, on land containing plenty of lime, ammoniacal nitrogen usually gives results as good as, or better than, nitrate nitrogen, but the latter form is to be preferred on soils seriously deficient in bases for crops which are susceptible to lime shortage.

Nitrate nitrogen is not retained in the soil and in any considerable downward movement of water it may be leached from the root zone. Ammoniacal nitrogen on the other hand is liable to no loss through rainfall and drainage, but ammonia nitrogen may be converted to nitrate nitrogen and thus indirectly lost from the soil by leaching. The slower action of ammoniacal nitrogen may be due in part to its becoming fixed firmly in the soil colloids and thus temporarily unavailable to plants, or in its being purloined by the nitrifying bacteria.

There is little doubt that the majority of farm crops can utilize both forms of nitrogen although most plants make quicker use of the nitrate. The grasses and cereals appear to be more efficient users of ammonia nitrogen than the green crops, roots, and clovers, although ammonia nitrogen usually

gives better results than nitrate on maincrop potatoes. Nitrate nitrogen has no acidifying effect on the soil, whereas all forms of ammonia nitrogen increase the natural loss of lime from the soil. This effect is seldom serious, but continued use of ammoniacal fertilizers on an acid soil will produce harmful effects on crops which cannot tolerate acid soil conditions.

It is impossible to assess the relative values of nitrate and ammonia nitrogen since they must vary so widely according to local circumstances. For most purposes choice should fall upon the cheaper form, and whenever one form is appreciably dearer than the other the use of the more costly type is only justifiable under special conditions and where the crop is a relatively valuable one. In this connexion it should be remembered that the quicker response frequently given to nitrate nitrogen is no indication that the ultimate increase in crop will not be bigger from ammonia nitrogen. In a very general manner nitrate nitrogen may be considered about 10 per cent. more effective than ammonia nitrogen, and on this basis nitrate fertilizers are not worth as much per cwt. as ammonia fertilizers. This may be verified by comparing the analyses of the various members of the two classes of these fertilizers at present available. It should be remembered, however, that this basis of comparison is inapplicable where it is particularly important to obtain a speedy result from applying nitrogen, although even in these conditions it is rarely justifiable to apply in the nitrate form the whole of the nitrogen the crop is to receive.

Phosphoric Acid (P_2O_5).

Phosphoric acid exists in the soil and is applied in fertilizers in combination with other materials in the form of phosphates. The effects of the first known phosphatic additions to the soil were so marked that the fertilizer industry in its early stages was almost entirely confined to the provision of phosphates; both nitrogen and potash fertilizers were developed later.

The effects of additions of phosphoric acid to soils in Britain are not generally nearly so great on crop yields as are those of nitrogen. Phosphoric acid tends to counterbalance the effects of extreme weather conditions and in a good season its influence may be very small indeed. Phosphatic manures also tend to prevent the undesirable effects of nitrogen which arise when the

latter is used alone or in excess, and largely for this reason phosphatic manures provide the basis for the manuring of fen soils.

Phosphoric acid greatly assists the early establishment and root development of crops, and this is its most valuable function. At a later stage excess of phosphoric acid may be disadvantageous since it encourages early maturity. In late districts this feature may be of great value, but on potatoes, sugar-beet, and cereals, especially if nitrogen be lacking, abundance of phosphoric acid may even lead to decreased yields. Such an effect is, however, unlikely to be common under agricultural conditions in this country, but the farmer may throw away money on phosphates more easily than on the other plant foods without being aware that his manuring is uneconomic. In Britain soils seriously deficient in phosphates are much rarer than those seriously lacking nitrogen or potash.

Phosphoric acid is not subject to loss by leaching to any important degree. The movement of water through the soil gradually takes the phosphoric acid deeper into the soil, but the movement is so slow that for practical purposes it may be disregarded, except possibly on a light sandy soil subject to heavy rainfall and where the phosphoric acid is applied in its most soluble form, i.e. ammonium phosphate. Crops do not remove large amounts of phosphates from the soil; the most important losses in this respect are from grain and live stock sold off the farm. Moreover, crops do not take up nearly so large a proportion of applied phosphoric acid as they do of nitrogen. Cereals remove about 25 to 30 lb. of phosphoric acid per acre; hay 15 to 20 lb.; swedes, turnips, and potatoes 30 to 40 lb.; beet 20 to 30 lb.; mangolds 40 to 60 lb.; clovers, beans, peas, and well-grazed pasture, each about 30 lb. These figures are based on average good crops and represent an annual removal from the soil of phosphoric acid equivalent to that in 2 cwt. of common superphosphate. Naturally on farms where crops are fed to live stock, much of the phosphoric acid is returned to the land in farmyard manure.

Forms of Phosphoric Acid in Fertilizers.

The forms in which phosphoric acid is applied to the soil are most conveniently classified on the basis of their solubility, since

practice has proved that this gives a very useful indication of their relative availability to crops. Phosphoric acid in a form soluble in water is the most rapid in action under most conditions, and this invariably holds true on neutral or alkaline soils. The phosphoric acid in ammonium phosphate and superphosphate is water-soluble, but under some conditions other forms of phosphate give equally good results. For this reason another method of testing solubility was introduced; a 2 per cent. solution of citric acid has been adopted on the assumption that this more nearly corresponds with the solvent power of the soil water. Basic slags are usually sold in accordance with the citric-acid test which gives a reliable indication of the value of different slags. On acid soils with a marked calcium deficiency, a high-soluble slag often gives results as good as, or occasionally even better than, a water-soluble form of phosphoric acid. To such soils the slag adds a small amount of calcium which may have considerable value, and the water-soluble phosphoric acid of superphosphate may become combined with alumina and iron and thus rendered slower in action than the citric-acid soluble phosphate of slag. Generally speaking, the more soluble forms of phosphoric acid are taken up by the crop to a greater extent than insoluble phosphoric acid.

The fineness of grinding also has an extremely important influence on the availability to plants of those forms of phosphoric acid which are not water-soluble. This is so widely recognized that basic slag and mineral phosphate are sold with a guarantee in regard to the fineness of grinding. The ground rock phosphates are not so rapid in action as water-soluble or citric-soluble forms, but in districts of high rainfall and on acid soils they are valuable, and on grassland under these conditions ground rock phosphates may ultimately give results as good as, though less rapid than, those from the more soluble types of phosphatic manures.

There have been pronounced differences of opinion as to the values of the solubility tests for phosphoric acid in fertilizers, but the standards adopted have provided useful guides for the farmer. Undoubtedly, however, the solubility tests do not fulfil all requirements and in other countries different tests are recognized, e.g. the citric-acid test is not regarded as giving a true indication of the value of certain processed forms of rock

phosphates or of ammoniated superphosphates. Although such fertilizers may seldom be offered to British farmers, information should be available which will enable a comparison to be made between citric-acid soluble phosphoric acid and phosphoric acid sold subject to other solubility tests.

Generally speaking, the soluble forms of phosphoric acid are used for arable crops, while grass which occupies the land for a relatively long period is manured with the slower-acting and more insoluble phosphatic fertilizers. Moreover, the latter types are most popular in the wetter parts of the country and on acid soils. Since there is practically no leaching of phosphates, it is in theory possible to apply in one operation sufficient phosphoric acid for several crops. Whether this is ever desirable is extremely doubtful and will be considered more fully in discussing the application of fertilizers.

Phosphates have little effect on the soil reaction, ammonium phosphate has a slight tendency to increase the acidity of the soil, while basic slag (containing both combined and free lime) has an appreciable influence in the opposite direction. The other phosphatic manures have little effect, and it should be mentioned that superphosphate does not increase soil acidity but in fact reduces soil 'sourness', which is apparently really due to phosphoric acid deficiency on certain markedly acid soils.

Potash (K_2O).

Potash completes the trinity of plant foods commonly supplied in artificial fertilizers, and it has a peculiarly close relationship with nitrogen in plant nutrition. Nitrogen and potash are to a large extent complementary in their action, each apparently enabling the plants to make better use of the other food.

Potash deficiency upsets the whole economy of the plant, and is especially manifest in reducing its efficiency in making starch; consequently potash is particularly important in the manuring of such crops as potatoes and mangolds, which produce relatively large amounts of starch per acre.

Sufficient supplies of potash also enable the crop to withstand drought better or to utilize more efficiently the available soil moisture. Potash would appear to be particularly valuable in reducing the liability to fungoid diseases of many crops. It has already been noted that excessive supplies of nitrogen tend to

produce a type of growth more liable to such diseases than where nitrogen is not abundant. This effect of excessive nitrogen may be counterbalanced to a large extent by the use of potash, and this corrective is of particular value in the manuring of fruits. In this respect also potash is of value in maintaining the carbohydrates (starches and sugars) in proportion to the nitrogen compounds in the plant, or in general terms potash tends to sustain the quality of the larger crops procurable by the use of nitrogen. Deficiency of potash may result in increased susceptibility to frost damage—an important consideration in fruit-growing and market-gardening.

Potash is removed by crops in larger amounts than either nitrogen or phosphoric acid, and good crops will abstract from the soil approximately the following quantities per acre: cereals 35 to 50 lb.; potatoes, beet, and turnips 100 to 150 lb.; mangolds 150 to 300 lb.; clovers, beans, peas, cabbages 75 to 150 lb.; hay 50 to 100 lb.

Potash in the majority of soils in Great Britain suffers little loss through drainage, but it is not retained so firmly as phosphates and appreciable losses through leaching may occur on sandy soils. For this reason and since all potassic fertilizers are water-soluble, and for other reasons which will be explained later, it is preferable to supply the potash requirements of each crop separately rather than to apply a heavy dressing intended for several years.

The effects of potash fertilizers are usually most marked on fens, chalks, and sands, whereas some clay soils give no response. It should be remembered that a heavy, acid soil, containing much colloidal matter, may require a heavier dressing of potash than a light soil before results are seen. Whether it would be profitable to apply a heavy dressing of potash under these conditions is another question, but in such cases lime should be given to reduce the soil acidity before applying potash. Liming in these circumstances would tend to make the potash subsequently applied in fertilizers and farmyard manure more available to the plant. Liming to excess, however, need not necessarily make the potash already in the soil more available, but might, in fact, have the opposite effect. On the other hand an application of potash will tend to render some of the lime in the soil colloids more available for plant use.

The ultimate effects of potash fertilizers on the soil reaction are negligible, but a heavy dressing of a potash fertilizer, especially if applied in drills just before seeding, may cause a temporary condition of the soil solution which would be harmful to seedlings.

All the potash fertilizers are soluble in water, but since potash is applied to the soil in combination with other materials it is necessary to distinguish between their influences, that is, to compare the so-called different forms of potash. The effect of the potash in the soil is regarded as always the same no matter in what compound it may be applied, but the other materials with which potash is associated in fertilizers have effects which will be considered in describing the individual fertilizers.

Calcium or Lime (CaO).

The object of liming is to correct the undesirable soil conditions that are associated with lack of lime rather than to provide the calcium required as a food by plants. Liming involves the application of calcium at considerably greater rates per acre than nitrogen, phosphoric acid, and potash, but calcium, although an essential plant food, is to be regarded chiefly as a soil-improving agent.

Deficiency of calcium is characteristic of acid soils, and the more acid the soil the less suitable it is for the growth of most agricultural crops. The degree of acidity of a soil is expressed by a notation of which pH 7 represents the neutral point; figures less than pH 7 indicate acidity, and pH 4, for example, represents a much more acid soil than pH 6. On the other hand, figures above pH 7 represent soils which are alkaline in reaction, and in Britain such soils always contain large reserves of lime. The extreme limits of cultivated soils are about pH 4·5 and pH 8·5, but the majority of crops thrive best in soils from pH 6 to pH 7·5. Some crops are capable of thriving on soils which are so acid that other crops cannot be successfully grown and the cropping must be adjusted to the degree of soil acidity or, alternatively, the latter must be corrected on the one hand by the use of lime on acid soils or by the use of acidifying fertilizers on alkaline soils. The following table indicates the range of soil acidity over which the various common crops will thrive best:

Barley . . .	pH 6·5 to 8	Turnips and swedes .	pH 5·5 to 7
Wheat . . .	pH 6 to 8	Sugar-beet . .	pH 6·5 to 7·5
Oats . . .	pH 5 to 6·5	Potatoes . .	pH 4·7 to 6·5
Rye . . .	pH 5 to 7	Red clover . .	pH 6 to 7·5
Beans . . .	pH 6 to 7·5	Lucerne . . .	pH 6·5 to 8
Peas . . .	pH 5·5 to 7	Lupins . . .	pH 4·5 to 6

All these crops can, of course, be grown outside the limits of soil reaction indicated in the above table, but the farther the reaction from these limits the more unfavourable for crop growth do the conditions become.

The acidity of the soil solution is not the only handicap to which crops on lime-deficient soils are subject, since soil acidity is associated with other conditions inimical to crop development. Lack of lime on clay soils is often associated with difficulties in cultivating; the clay is sticky when moist, and under rapid drying influences tends to cake quickly on the surface. The incorporation of adequate amounts of lime or chalk improves such soils by binding the fine clay particles into 'crumbs', thereby producing a more open texture with better drainage and aeration of the soil. This in turn enables the land to be cultivated more easily, a good tilth is obtained with less difficulty, and more fertile conditions are secured for crop growth.

On many soils, particularly of the heavier types, lime deficiency appears to result in the conversion of compounds of alumina to a state which is detrimental to crop growth. This effect is probably chiefly due to phosphate starvation arising from the combination of alumina with the phosphate in the soil, thereby making it largely unavailable to plants. This condition is known as 'sourness', and while it only occurs on acid soils, it will be appreciated that all acid soils are not necessarily 'sour'. Thus of two soils having the same degree of acidity, one which exhibited symptoms of sourness might require larger quantities of lime to procure fertile conditions than would be necessary on the soil showing no sourness. Generally speaking, more lime is required to correct acidity on heavy soils than on light soils, but since on the latter class lime is more easily washed out, more frequent and smaller applications are required on light soils. Thus, as a general guide, the following amounts of lime have been suggested as necessary on different classes of soils to correct the acidity, that is, to raise the pH to 7, the

neutral point. (Hardy and Lewis, *Jour. Agric. Science*, xix. 1, 17, 26.)

	Sands.		*Loams.*		*Silts.*		*Heavy Clays.*	
	Tons	cwt.	Tons	cwt.	Tons	cwt.	Tons	cwt.
pH 4 . .	5	0	8	0	10	0	12	4
pH 5 . .	2	18	4	6	5	4	6	12
pH 6 . .	1	6	1	14	2	4	3	0

Lime deficiency results in infertile soil conditions since soil acidity is inimical to those bacteria whose activities are associated with fertility. When lime is lacking, the decomposition of organic matter is upset, the organic nitrogen is not rendered available for use by plants, and the semi-decayed organic matter may become harmful, as exemplified by the development of a 'mat' on grassland. On heavy clay soils seriously deficient in lime, soluble phosphates may be converted to forms which are less available to plants, as previously noted. On the other hand an application of lime to such acid soils appears to render the soil phosphates more available for crop growth.

Although a deficiency of lime, even when other plant foods are in abundance, may be the cause of poor crops, it is also important to note that an excess of lime may result in unsatisfactory yields. For each soil and crop there is a happy medium, though poor crops are much oftener due to lack of lime than to excess of it. Apart from a chemical examination of the soil, lime deficiency is manifest by many symptoms of crop growth. Red clover, lucerne, barley, sugar-beet, beans, and wheat are crops which readily indicate soil acidity by unsatisfactory growth. Red clover fails to 'take' and 'stand', barley 'goes off' in patches in the early stages of development, the leaves having a yellowish or even reddish appearance at the tillering stage. Much the same applies to wheat which is, however, not so susceptible as barley to soil sourness. Crops of the turnip and cabbage family are particularly liable to the disease known variously as 'finger and toe' or 'club-root', which is rarely found except on acid soils and may be eradicated in time by liming. Profusion of weeds is often typical of acid land, especially when spurrey, sheep's sorrel, or corn marigold predominate. On grassland, lime deficiency is nearly always indicated by the presence on the surface of a 'mat' of undecayed herbage, although proper cultivation and grazing should prevent the development of a

'mat' irrespective of the lime condition of the soil. Common weeds of grassland suffering from lack of lime are sour-dock, tormentil, bracken, and field woodrush, together with absence of clovers and preponderance of fine-leaved wiry grasses.

Excess of lime encourages 'common scab' disease of potatoes, 'foot-rot' of wheat, and 'crown-rot' of sugar-beet. Each crop or plant species has, in fact, a range of soil acidity most suited to its development, and it is because marked soil acidity is so extremely common in this country that the dangers of over-liming are rarely considered. The question of liming must always be decided by the crops it is intended to grow as well as by the condition of the soil. On soils containing abundance of lime the ammoniacal form of nitrogen should generally be preferred to the nitrate form, and where it is desired to reduce soil alkalinity drastically for a special purpose, sulphur or sulphuric acid may be used. Excess of lime to a degree deleterious to crop production is scarcely yet admitted to be of practical moment in British agriculture, but its possibility serves to emphasize the imprudence of applying lime in excess of the immediate needs of the crops it is intended to grow.

On the majority of soils the principal loss of lime is through the drainage water, and the heavier the rainfall and the greater the amount of lime in the soil, the bigger is the annual loss. Lime is lost more rapidly from sandy soils than from those of closer texture, and the losses are increased in industrial districts where the rain washes into the soil the acid-forming materials present in a smoky atmosphere. In a district of heavy rainfall on a soil well supplied with lime the annual loss through drainage may reach 5 to 6 cwt. of quicklime per acre. On the other hand, on a soil already depleted of lime this loss will be much smaller, and obviously the lower the rainfall, other conditions being equal, the less will be the quantity of lime removed annually in the drainage water.

The amounts of quicklime (CaO) removed by crops are relatively small, especially since in cereals it is chiefly in the straw and is therefore usually returned to the land. Hay, particularly clover and lucerne hays, sold off the farm is the biggest source of loss of lime through crop production. In any event no crop is likely to remove more than 1 cwt. per acre. It is often emphasized that 1 cwt. of sulphate of ammonia removes

about one-half cwt. of quicklime and that continued use of sulphate of ammonia may thereby impoverish the soil. Although the increased loss through the drainage water incurred with ordinary rates of application of ammonia nitrogen is only a third or a quarter of the natural loss, the sulphate of ammonia produces bigger crops which not only themselves remove larger amounts of lime from the soil, but in addition larger amounts of potash and other plant foods. Consequently the careless use of ammonia nitrogen is one of the commonest examples of unbalanced manuring, which is so outstandingly obvious merely because the majority of British soils are naturally prone to loss of lime and other bases.

On the other hand some fertilizers tend to diminish the losses of lime from the soil, and on acid soils such fertilizers are of particular value. In this regard the influences of each manure on soil acidity will be indicated in the description of the individual fertilizers which will be given later. In the reduction of soil acidity basic slag is a most valuable fertilizer since it is generally applied in relatively large dressings per acre and it contains more calcium than any other fertilizer; in practice, 1 cwt. of slag has almost the same effect on soil acidity as three-quarters of a cwt. of chalk or ground limestone.

Forms of Lime.

Lime may be applied to the soil in three forms—the oxide, the hydroxide, and the carbonate. Calcium oxide is the form commonly known as quicklime or burnt lime and may be purchased in three grades: lump lime (also known as cob lime and shell lime), ground lime which is lump lime ground to a powder, and 'small lime' which is the residue from the kilns after picking out the lump lime; small lime thus contains varying amounts of clinkers and cinders from the kiln.

Quicklime or calcium oxide is the most concentrated form in which lime can be applied to the soil. On exposure to air quicklime absorbs moisture and becomes converted to slaked lime, consequently quicklime cannot be stored without difficulty. This is particularly true for ground lime which is supplied in bags, since the latter burst and burn as the quicklime swells and generates heat through taking up moisture from the air. Quicklime contains about 80 per cent. more calcium than carbonate

of lime, and hence where long hauls by rail and road are involved it is generally the cheapest type of lime when all costs on to the field have been taken into account. The caustic action of quicklime may be harmful to plants, hence this form of lime should be applied during the dead season on grassland and a week or two before seeding on arable land. There is no great danger, however, in applying light dressings of ground lime to winter cereals before spring tillering. Generally speaking, quicklime gives most satisfactory results on heavy and peaty soils, whereas on light land it is usually preferable to use carbonate of lime.

Quicklime which has taken up moisture becomes calcium hydroxide, hydrate of lime, or slaked lime. When quicklime in lump or 'small' form is used it is usually allowed to slake in heaps before spreading. The slaking of lime gives a fine powder, and the finer the particles the more rapid and effective their action in the soil. Slaking on the field naturally saves the cost of freight and carting of the water used in slaking. Slaked lime is supplied in bags and is generally a very pure form of lime, but is high in price and its users are chiefly horticulturists and market-gardeners. It is a clean, safe, and very effective form in which to apply lime; it may be stored easily and has no scorching action. It may be applied therefore when the land is under crop, is suitable for all classes of soil, and may be expected to have a quicker effect than carbonate of lime. It is also a suitable diluent of dusts for pest control.

Carbonate of lime is the form in which lime is found in nature and includes various types of limestone and chalk. When limestone or chalk is burnt, carbon dioxide gas is expelled, leaving calcium oxide. It has been stated above that calcium oxide takes up water to form hydrate of lime, and the latter in turn gradually takes up carbon dioxide from the air and soil and thus once more becomes calcium carbonate. Carbonate of lime is applied to the soil in four forms: ground limestone, ground chalk, lump chalk, and various waste types of calcium carbonate from industrial processes—the so-called 'by-product limes'.

The value of the various forms of carbonate of lime depends almost entirely on the fineness of grinding and the amounts of calcium they contain. If limestone or chalk be ground so finely as slaked lime, i.e. so that over 95 per cent. passes through the

standard 100-mesh sieve, it will give results approximately equal to those given by slaked lime, supplying the same amount of calcium per acre. Carbonate of lime has no burning action and consequently can be applied without damage to the crop, can be easily stored, and presents no difficulties in application. Carbonate of lime is a form well suited to sandy soils and for application to growing crops.

Certain forms of limestone contain large quantities of magnesium and such limestones when burnt may have a definitely harmful action. Dressings exceeding two tons per acre should only be applied when the effects of such lime on the particular type of soil are known. There is most danger from burnt magnesium limes on light soils and on arable land, whereas on heavy and peaty soils and 'matted' grassland there is little to fear.

Waste carbonate of lime from various manufacturing processes is often to be had very cheaply, and provided the farmer obtains a guarantee that it contains nothing poisonous to plants or deleterious to the soil, such lime is valuable since it is invariably in a finely divided state when dry. Most waste limes, however, contain large amounts of moisture and their values can only be decided by comparing the unit cost of calcium on to the field with the unit cost in standard agricultural limes.

The application of lime and the valuation of the various types of lime will be considered subsequently.

CHAPTER III

NITROGENOUS FERTILIZERS

Sulphate of Ammonia. Formula: $(NH_4)_2SO_4$.

The sulphate of ammonia first used in agriculture was obtained from gas works and coke-oven plants, and while these sources of production are still important a large proportion of ammonium sulphate is manufactured to-day by various synthetic processes.

Gas works and coke-oven sulphate of ammonia is made by neutralizing sulphuric acid with the ammonia driven off from the coal. The ammonium sulphate is obtained in crystalline form, the size, shape, and colour of the crystals varying with slight modifications in manufacture. Sulphate of ammonia from these sources is usually termed 'by-product' to distinguish it from the 'synthetic' product.

By-product ammonium sulphate is of two kinds, known respectively as 'ordinary' and 'neutral'. They differ in the amount of free sulphuric acid they contain; works which produce 'neutral' quality take special steps to remove free sulphuric acid from the ammonium sulphate crystals. The difference in nitrogen content between the two kinds is slight, but there is a legal distinction in that sulphate of ammonia containing more than 0·025 per cent. of free acid in terms of sulphuric acid cannot be sold as 'neutral'. In fact, there is nowadays very little 'ordinary' quality made since very few works continue to operate on such old-fashioned lines. 'Synthetic' sulphate of ammonia is always of neutral quality.

The 'ordinary' quality is very often wet, since it takes up moisture and becomes sticky and is then difficult to sow evenly by hand or machine. On the other hand, the size of crystal is often larger than that of 'neutral' by-product material, and on this account 'ordinary' was sometimes preferred. The free acid, however, rots the bags and consequently 'ordinary' is unsuitable for storage, although it does not cake to the same degree as some types of 'neutral' quality with fine crystals. The latter is usually a white crystalline salt, readily friable and free running, does not take up atmospheric moisture to any serious

degree, and stores well, apart from the possibility of caking when stored in large piles for some length of time. Several 'makes' of neutral quality with large and regular-sized crystals are now obtainable.

So far as the farmer is concerned there is no difference in the value of the 'ordinary' and 'neutral' qualities apart from the features arising out of their physical condition, e.g. the finer 'neutral' types might produce more scorching on wet foliage than the coarser 'ordinary' which would not stick so readily to the leaves. There is a slightly lower percentage of nitrogen in 'ordinary', but this is of no practical significance since it never amounts to more than 3 or 4 lb. per acre with normal rates of application.

Neutral sulphate of ammonia contains from 20·5 to 21 per cent. of nitrogen, a few works guaranteeing the higher figure, but so far as the agricultural user is concerned the difference is not of the slightest importance. Each cwt. of sulphate of ammonia thus supplies 23 lb. of nitrogen in the ammoniacal form. The sulphate portion comprises about 75 per cent. of this fertilizer, and as this component usually does more harm than good, it illustrates a point that applies to many of the old established fertilizers—the farmer pays carriage, handling, and distribution charges on material that is generally useless to him in order to secure a small quantity of plant food.

Sulphate of ammonia supplies nitrogen in the ammonia form, the attributes of which have been previously considered. Like all ammoniacal fertilizers it is generally, but not invariably, slower and more gradual in its action on plants than nitrate fertilizers. The nitrogen is fixed in the soil in the ammonia form, and is later utilized by crops or converted to nitrate. Of that converted to nitrate all may be used by plants or some may be washed out of the soil. Consequently sulphate of ammonia is generally safer than nitrate fertilizers for use in rainy districts or during seasons of the year when considerable rainfall may be expected before the plant is likely to make full use of the fertilizer.

The sulphate portion of ammonium sulphate combines with calcium in the soil to form calcium sulphate which is removed in the drainage water. This naturally causes a loss of lime from the soil as a result of applying ammonium sulphate, a point

which has already been discussed. Sulphur is, however, an essential food of plants and on some soils it is necessary to apply this nutrient, but British soils are invariably well supplied with it.

If sulphate of ammonia is broadcast on wet foliage so that the fertilizer adheres to the leaves, severe scorching is likely to result; advantage of this character is taken in applying sulphate of ammonia to lawns where it lodges on the broad leaves of weeds but does no permanent harm to the grasses. It may also be used as a liquid spray for the eradication of broad-leaved weeds in cereal crops.

In buying sulphate of ammonia there are only two points to which attention need be paid. The purchaser should know if he is offered 'neutral' or 'ordinary' quality, and if the fertilizer is to be broadcast in the pure state, a good-sized, free-running crystal is most desirable. On the other hand, if the sulphate of ammonia is to be mixed with superphosphate or some other powdery material, then a fine crystal is required.

Ammonium Chloride. Formula: NH_4Cl.

This fertilizer has not yet been generally offered in the home market, but has been used regularly for some years in other countries, and at some future date it may be available to British farmers. It may be manufactured in much the same manner as sulphate of ammonia, but using hydrochloric acid or chloride in place of sulphuric acid or sulphates, or by the Solvay process for the production of sodium bicarbonate.

Ammonium chloride is a white or yellowish salt, indistinguishable in appearance from some makes of ammonium sulphate. Ammonium chloride is slightly richer in nitrogen than the sulphate and is usually guaranteed to contain $25\frac{1}{2}$ or 26 per cent. of nitrogen, and thus a cwt. of ammonium chloride supplies $28\frac{1}{2}$ lb. of nitrogen, or $5\frac{1}{2}$ lb. more than in 1 cwt. of sulphate of ammonia. The difference in nitrogen content is of small practical moment except where dressings of about 2 cwt. and upwards per acre are in view, and for most purposes an equal weight of one fertilizer can be substituted for the other. Ammonium chloride, however, is more corrosive than ammonium sulphate.

Ammonium chloride may be used in the same manner and

for the same purpose as ammonium sulphate, except for potatoes and fruit, which sometimes suffer from the application of chlorides. The chloride part of ammonium chloride behaves in the soil like the sulphate part of ammonium sulphate, i.e. the chloride combines with calcium and is washed out of the soil as calcium chloride. Thus the use of ammonium chloride increases the loss of lime from the soil in the same manner as sulphate of ammonia.

There is a certain amount of evidence to indicate that cereal crops, more particularly barley, give a better response to ammonium chloride than to the sulphate, but the difference is in any case very small even if it can be regarded as generally established.

A mixture of ammonium chloride and calcium carbonate is sold on the Continent under the name of Kalkammon and contains 17 per cent. of nitrogen and 30 per cent. of calcium carbonate.

Ammonium Phosphate. Formulae: (1) $(NH_4)H_2PO_4$;
(2) $(NH_4)_2HPO_4$.

Ammonium phosphate is manufactured and sold as a fertilizer in two forms, (1) mono-ammonium phosphate, and (2) di-ammonium phosphate, the former containing from 12 to $12\frac{1}{2}$ per cent. of nitrogen and the latter 21 per cent. of nitrogen. Both materials are readily soluble in water, and of course they supply the plant with phosphate in addition to nitrogen. A cwt. of the mono-salt supplies $13\frac{3}{4}$ lb. of nitrogen, and a cwt. of di-ammonium phosphate supplies 23 lb. of nitrogen. Their phosphate contents will be considered along with those of other phosphatic fertilizers in the succeeding chapter.

The ammonium phosphates are products of large-scale fertilizer manufacture, the ammonia being obtained by one of the various synthetic processes. The mono-ammonium phosphate is obtained by reaction between ground mineral phosphate, sulphuric acid, and sulphate of ammonia, which gives a solution of mono-ammonium phosphate. The commercial product contains small amounts of sulphate of ammonia which increases the nitrogen slightly over the 12·2 per cent. which is the content of chemically pure ammonium phosphate.

Ammonium phosphates are white crystalline materials indis-

tinguishable in appearance from a good brand of sulphate of ammonia, and in fact the two fertilizers are frequently mixed to increase the proportion of nitrogen to phosphate. Granulated forms are being manufactured more extensively. The crystals are fine in some types of ammonium phosphate, and if applied to wet foliage severe scorching usually follows, unless the fertilizer is immediately washed off by rain. The precautions to be observed to obviate scorching with sulphate of ammonia apply equally to finely crystalline ammonium phosphate. Ammonium phosphate and ammonium sulphate mixtures come within the definition of compound fertilizers in the Fertilizers and Feeding Stuffs Act of 1926.

The nitrogen in ammonium phosphates acts in a similar manner to the nitrogen in other ammonium fertilizers and is suitable for the same conditions and purposes. The ammonium phosphates are termed 'high-grade' fertilizers since they supply nothing the soil and crops do not require, and involve no charges for the transport and handling of inert and unwanted materials.

Like all ammonium fertilizers the ammonium phosphates tend to increase soil acidity, but only to about half the extent of sulphate of ammonia, and their effect on the soil reaction may be regarded as negligible under ordinary circumstances. On acid soils the ammonium phosphates are likely to be relatively less efficient than on soils not deficient in lime.

Ammonium Nitrate. Formula: NH_4NO_3.

Ammonium nitrate contains 35 per cent. of nitrogen, half of which is in the ammoniacal form and half in the nitrate form, and from many standpoints it is the ideal nitrogenous fertilizer. Ammonium nitrate, however, suffers from two drawbacks, so serious as to preclude the use of the pure salt as a fertilizer. It is used in the manufacture of explosives and may itself explode under some conditions, and it has such an extreme avidity for moisture that it would present insuperable difficulties in distribution for use on the farm. Consequently ammonium nitrate for use as a fertilizer is processed to avoid both danger from explosion and the difficulties arising from its rapid absorption of moisture. Ammonium nitrate is sold as a fertilizer in the British market under the trade name of Nitro-Chalk, which contains 45 per cent. of ammonium nitrate.

Nitro-Chalk.

This is another product of the synthetic nitrogen industry and consists essentially of a mixture of ammonium nitrate and by-product calcium carbonate in approximately equal proportions. Nitro-Chalk was first marketed in the form of a white, powdery material, but this has been replaced by a granular product, grey in colour. Nitro-Chalk contains 15½ per cent. of nitrogen—half as ammonia and half as nitrate—and 1 cwt. thus supplies about 17½ lb. of nitrogen. Nitro-Chalk must be sold as a compound fertilizer in accordance with the Fertilizers and Feeding Stuffs Act of 1926. The granulation has largely surmounted the tendency to set or cake, to which ammonium nitrate is particularly liable. The present-day product is usually very free running, the granules being about half the size of a plump wheat grain and in an excellent form for sowing by machine or by hand.

For general use Nitro-Chalk is to be regarded as the nearest approach to the ideal nitrogenous fertilizer. It provides nitrogen in two forms, is in excellent physical condition, and has practically no effect on the soil reaction, i.e. it does not tend to make the soil either more acid or more alkaline, though on lime-deficient soils the chalk is of definite value. It contains nothing but plant foods generally required and has no detrimental effect on soil tilth. No other nitrogenous fertilizer has all these desirable features, and under almost all conditions where nitrogen is required it may be supplied in the form of Nitro-Chalk.

The action of Nitro-Chalk on the plant should, in theory, be intermediate between those of sulphate of ammonia and nitrate of lime or nitrate of soda. In practice this is very largely true; Nitro-Chalk is the 'happy mean' of nitrogenous fertilizers. Its composition ensures that it will never be extreme in its effects and it may be depended upon to give results wherever any nitrogenous fertilizer will assist the crop.

The danger of scorching foliage is reduced by the granular form of Nitro-Chalk, but should the granules lodge on the leaves then, as with all inorganic nitrogenous fertilizers, scorching may occur. The granular condition considerably lessens the tendency to caking in storage, to which all inorganic nitrogenous fertilizers are liable.

There are other methods of utilizing ammonium nitrate as a fertilizer, and of these the most important is the German product, ammonium-sulphate-nitrate or 'Leunasalpeter'. This is a greyish-white crystalline salt, similar in appearance to many samples of sulphate of ammonia, and contains 26 per cent. of nitrogen, of which a quarter is in the nitrate form and the remainder ammoniacal. A cwt. of ammonium-sulphate-nitrate thus contains 29 lb. of nitrogen. This fertilizer has a slightly acidifying effect on the soil which is, however, not quite equal to that of sulphate of ammonia. Although really a double salt, for practical purposes ammonium-sulphate-nitrate may be looked upon as a mixture of 37 per cent. ammonium nitrate and 63 per cent. ammonium sulphate.

Another continental ammonium nitrate fertilizer is Kalkammonsalpeter containing 20·5 per cent. of nitrogen in equal proportions of ammonia and nitrate, and 35 per cent. of calcium carbonate. There is also a variety of mixtures of ammonium nitrate and calcium sulphate.

Sodium Nitrate. Formula: $NaNO_3$.

This product contains either $15\frac{1}{2}$ or 16 per cent, of nitrogen, all in the nitrate form. Thus 1 cwt. contains $17\frac{1}{2}$ to 18 lb. of nitrogen, and 27 per cent. of sodium, equivalent to 62 lb. of sodium carbonate in the pure salt.

Nitrate of soda is one of the oldest nitrogenous fertilizers and farmers are as familiar with it as with sulphate of ammonia. For many years nitrate of soda was entirely derived from natural deposits in Chile, but with the development of the synthetic nitrogen industry, nitrate of soda is now produced in England and in several other countries. Moreover, natural deposits are known outside South America, but it is doubtful if they can ever be worked sufficiently cheaply to compete with the synthetic product.

The forms in which nitrate of soda is now marketed are so diversified that three or four quite distinct descriptions can be given. The product which farmers have long used is variously tinted, coarsely crystalline, very liable to set hard, and to take up moisture and become sticky. In recent years a granular form of nitrate of soda has been placed on the market and is much superior in condition to the older product. The synthetic nitrate

of soda is very much like sulphate of ammonia in size of crystal, may vary in colour, and, like granular nitrate of soda, it does not tend to become wet and sticky nearly so easily as ordinary Chilean sodium nitrate. The latter usually contains traces of iodine, but there is no evidence that this is of any value on soils in this country.

Nitrate of soda, like all fertilizers containing nitrate nitrogen, is usually rapid in action, its effects being noticeable in the appearance of the crop a few days after application. Since all the nitrogen is in nitrate form in this fertilizer, it is not so certain in action as ammonia fertilizers during periods of heavy rainfall, but except on light sandy soils it is most unlikely that nitrate is washed out of the soil to the extent that is quite commonly supposed. There is little fear of much loss until the drains begin to run after a persistent and heavy fall of rain. The general effects of nitrate nitrogen have already been considered, but the sodium contained in nitrate of soda is also of considerable importance.

To some extent the sodium can take the place of part of the potassium absorbed by plants and may thus be of value on soils deficient in potash and for crops requiring relatively large amounts of this food. Moreover, soda is a base and on acid soils nitrate of soda gradually reduces acidity since its effect is cumulative. So far as correcting acidity is concerned, a single application of this fertilizer has a practically negligible effect, but for crops susceptible to acidity which are grown on soils lacking lime, nitrate of soda is a most useful form in which to supply nitrogen. On heavy soils the sodium may be a definite disadvantage since it tends to break up the clay crumbs, resulting in a soil which is sticky when wet and liable to cake quickly on the surface under drying weather conditions.

The use of nitrate of soda is largely confined to the top-dressing of established crops and it is particularly suitable for sugar-beet, mangolds, and market-garden crops of the cabbage family, to which it often gives a better colour than other nitrogenous fertilizers unless ample potash is available.

Calcium Nitrate. Formula: $Ca(NO_3)_2$.

Nitrate of lime, in the form sold for use as a fertilizer, at one time contained 13 per cent. of nitrogen, all in the nitrate form;

equivalent to 14½ lb. of nitrogen in 1 cwt. of the fertilizer. It also contained about 24 per cent. of calcium oxide and the total calcium content was about 42 per cent. This type of nitrate of lime is manufactured by the electrical process, and consists of dark-grey, angular granules which take up moisture from the air so readily that the material can only be marketed in air-tight barrels. The product is unpleasant to handle, and in order to surmount these drawbacks nitrate of lime is now chiefly manufactured by another process which includes the addition of about 5 per cent. of ammonium nitrate. The newer form is white in colour, the granules smaller and rounder than those of the older form of nitrate of lime, and it can be safely transported and stored in bags; nor does it become wet and sticky so rapidly during application. The white nitrate of lime contains 15½ per cent. of nitrogen, of which 14½ per cent. is in the nitrate form and 1 per cent. in the ammonia form, and it also contains about 28 per cent. of calcium oxide and practically the same total calcium content as the grey nitrate of lime. Apart from the difference in the nitrogen content and the superior physical condition of the white nitrate of lime there is no difference in action between the two forms.

Under dry conditions, nitrate of lime is usually more rapid in its visible effect on the crop than any other nitrogenous fertilizer, and for this reason calcium nitrate is used as a top-dressing on market-garden crops in the dry south-eastern counties of England.

Nitrate of lime is unpleasant to handle and during hot weather when the workers perspire it may severely burn the skin of the hands and arms, which should therefore be smeared with oil or vaseline. These effects, and the possibility of scorching the crop, are considerably lessened during rainy weather, and many growers prefer to take advantage of a light rain when applying this fertilizer.

The lime content of nitrate of lime is of value on sour soils where, for most crops, the nitrate form of nitrogen is the most efficient. Calcium nitrate has approximately the same corrective influence on soil acidity as an equal weight of sodium nitrate, but the former has no bad influence on soil tilth.

Nitrate of lime takes up moisture more readily than any other nitrogenous fertilizer, hence the containers for transport are

waterproof, and if the material is to be stored on the farm care must be taken to store in a very dry situation. A cask or bag once opened should always be used and not put back into store. The granular condition of the fertilizer facilitates good distribution by hand or machine and, provided it has not become sticky, there is small risk of the fertilizer lodging on the foliage.

Potassium Nitrate. Formula: KNO_3.

This material is manufactured by some synthetic nitrogen plants and is obtained from nitrate deposits in Chile, India, and other countries. The commercial pure salt contains about 13·8 per cent. of nitrogen, but the material sold for use as a fertilizer is variable in composition and in its nitrogen content, hence this fertilizer should only be purchased on a guaranteed analysis of each parcel. Potassium nitrate is crystalline and absorbs moisture less readily than sodium nitrate, and hence is not so likely to lose condition during transport and storage. It is a valuable combination of nitrogen and potash and contains little that is inert or useless. There is, in fact, some evidence to indicate that this combination of potassium is more efficiently utilized by plants than the other potash fertilizers. It has already been explained that the effects of nitrogen and potash in plant nutrition are interrelated and to some extent complementary, and hence potassium nitrate is a valuable fertilizer for market-garden crops and fruit where the quality of the produce is especially important. Nitrate nitrogen should be largely reserved for top-dressing, and it is generally considered the best policy to apply all the necessary potash with the other ingredients in the basal dressing before sowing or planting the crop. There is, however, little evidence to justify this generally accepted principle even for farm crops, and for market-garden crops which receive several applications of nitrogen some growers make it a practice to top-dress with potash also.

Calcium Cyanamide. Formula: $CaCN_2$.

Cyanamide contains from 18 to 24 per cent. of nitrogen and as sold in the British market is guaranteed to contain 20·6 per cent. of nitrogen, or 23 lb. in 1 cwt. of cyanamide. Pure calcium cyanamide contains 35 per cent. of nitrogen, but the commercial

cyanamide contains about 60 per cent. $CaCN_2$ mixed with carbon and various calcium compounds of which slaked lime is the most important.

Calcium cyanamide is made by passing nitrogen through electrically heated furnaces containing calcium carbide. The fused mass is ground, treated with moisture to remove any free carbide, and then oiled to overcome the dustiness which was formerly one of the great disadvantages of this material. The dust is poisonous and may have very disagreeable effects, even on men using the material out of doors. It is also manufactured in granular form, though this is only a recent development. The cyanamide process utilizes much more energy per unit of nitrogen fixed than the synthetic ammonia process, and hence cyanamide manufacture is confined to situations where cheap and surplus electrical energy is available.

The effects of an application of calcium cyanamide are very variable and depend largely upon the biological, chemical, and physical condition of the soil. Under the best conditions where good aeration and sufficient moisture exist with high biological activity the cyanamide is rapidly converted to urea, but in other circumstances the use of cyanamide may be attended with disadvantages. If the soil be too wet or too dry, or lacking in bacteria or colloidal matter, cyanamide may be very slow in action or even have a harmful effect on the crop. On some soils cyanamide appears to upset the normal nitrifying action, and until this effect has disappeared little or no benefit is obtained. If the cyanamide becomes damp before application to the soil dicyandiamide is formed, a substance which is very toxic to plants. Moreover, in humid surroundings cyanamide may lose nitrogen. Consequently, it is never advisable to store this fertilizer for lengthy periods on the farm and delivery should as far as possible be arranged to coincide with the time of application.

The free ammonia given off by cyanamide in the soil may have an injurious effect on germinating seeds, and it should be used as a top-dressing only on cereals. To avoid danger to the crop, cyanamide should be thoroughly incorporated with the soil two or three weeks before sowing seeds and on grassland should be applied preferably when rain is falling, as this fertilizer scorches foliage very readily. This feature, however, may be turned to advantage in the destruction of charlock in cereal

crops, though for this purpose powdery cyanamide is the most effective.

In knowledgeable hands and under the right conditions calcium cyanamide is a very useful fertilizer and is widely employed on the Continent. It is the slowest in action of all the inorganic nitrogenous fertilizers and is of most interest to farmers whose soils are lacking in lime. Cyanamide contains about 20 per cent. of lime in addition to the calcium combined with nitrogen; the total calcium is equivalent to about 60 per cent. of calcium oxide. Calcium cyanamide thus tends to counteract soil acidity and in this respect is easily the most efficient of the nitrogenous fertilizers, being much more effective than equal weights of nitrate of lime or nitrate of soda.

If cyanamide is to be applied by hand the skin should be protected with oil which should be wiped off immediately the work is finished and before washing. When sown with a fertilizer drill the implement should be particularly well cleaned after use. It is inadvisable to work for long periods under circumstances where the dust of cyanamide is likely to be inhaled continuously.

Small amounts of calcium cyanamide are often used in compound manures, for which purpose it is a valuable 'conditioner'.

Urea. Formula: $CO(NH_2)_2$.

This fertilizer is a white, crystalline, synthetic product of the chemical industry and the pure substance contains 46·7 per cent. of nitrogen. The commercial material is sold with a guarantee of 46 per cent. of nitrogen, equivalent to 51½ lb. of nitrogen in 1 cwt. of the fertilizer, and is thus much the richest in nitrogen of all fertilizers. Indeed 1 cwt. of urea contains as much nitrogen as 4 or 5 tons of farmyard manure. Urea is manufactured from liquid carbon dioxide and liquid ammonia which are heated to high temperature under pressure. A fused material is obtained from which urea is leached in water, and the solution is distilled, filtered, and evaporated to yield commercial urea.

Neither ammonia nor nitrate nitrogen is present in urea, all the nitrogen being in the amide form which is essentially organic. Thus urea, along with cyanamide, occupies a place somewhat midway between the ammonia fertilizers and those animal and vegetable materials which are usually termed organic manures.

Urea is not usually quite so rapid in action as the nitrate and ammonia fertilizers but distinctly quicker than cyanamide and most of the 'organics'. Urea contains no injurious ingredients and its effect on the soil reaction is very slight. It is completely soluble in water but is not washed out of the soil and has no influence on the physical characters or texture of soils. It is not absorbed by soils but is rapidly decomposed and the nitrogen converted to the ammonia form.

Urea is stored and transported more easily than many nitrogenous fertilizers and presents no difficulties in application although it takes up moisture from the air fairly quickly. It is, however, in fine crystalline condition and will stick to wet foliage and cause scorching unless applied when the plants are dry. Generally speaking, however, urea is incorporated with the soil before seeding rather than used as a top-dressing. Moreover, owing to its very concentrated nature urea presents difficulties in securing even distribution, as little more than ½ cwt. per acre is necessary for many crops.

A double salt of urea and nitrate of lime is also manufactured on the Continent, containing 34·3 per cent. of nitrogen, of which about 7 per cent. is in nitrate form and the remaining 27·3 per cent. in amide form. This product, termed Calurea, also contains 13·5 per cent. of calcium oxide.

ORGANIC NITROGENOUS FERTILIZERS

A large variety of substances can be included in this classification, some of which are widely used, especially by market-gardeners. For the ordinary farmer these materials can be seldom of interest since they usually contain relatively small amounts of plant foods, and often these are not in very available form. Where farmyard manure is regularly used, or where temporary leys occur in the rotation or on soils containing much humus, these organic fertilizers should be valued solely on the cost per unit of plant food on to the field as explained subsequently.

Organic manures are slower in action but perhaps more foolproof than the inorganic fertilizers, and on some kinds of market-garden crops which bring large returns and which appear to thrive best on 'stored-up fertility', the organic fertilizers may justify the higher price which is usually charged for the plant

foods in these manures. The residual values and the more prolonged action of organic manures are, however, commonly over-estimated.

In some localities it is possible to obtain waste organic materials sufficiently cheaply on to the farm to justify their use as fertilizers, but all such materials should only be bought on the basis of analysis and with the knowledge that the plant foods will become available in the soil and that the materials contain no harmful substances. Many of the organic fertilizer materials are incorporated in small amounts in mixed or compound fertilizers which are thereby given a more open texture and maintain a friable condition.

Although some animal substances may have a small influence upon the texture of the soil, as, for example, shoddy in large quantities, they should not be regarded as similar in this respect to vegetable products, since these decompose to form humus. Both, however, are dependent upon bacterial action to convert them into materials which are available to plants.

Guano.

This material consists of the residues of the excreta of fish-eating birds, and in accordance with the provisions of the Fertilizers and Feeding Stuffs Act the vendor must state the amounts of nitrogen, phosphoric acid, and potash in guano. Samples of fairly recent origin may contain up to 15 per cent. of nitrogen, but older deposits which have been subject to much weathering may contain only traces of nitrogen. In the purchase of guano, therefore, the analysis is all-important since on it depends how the fertilizer is to be used. The guanos containing little nitrogen are generally darker brown in colour and have less odour than those rich in nitrogen.

Guano is sometimes mixed with other materials to raise the percentage of nitrogen, but the mixture must be sold as a compound fertilizer.

The phosphate content of guano varies inversely with the nitrogen, a sample containing little nitrogen may contain up to 25 per cent. of phosphoric acid (P_2O_5), while in a highly nitrogenous guano the phosphoric acid may be as low as 6 or 7 per cent. The potash in guano varies from 2 to 6 per cent.

Guano in dry and friable condition is a very useful fertilizer,

but must be valued and used solely on the amounts of the three plant foods it contains. It is quick in action in comparison with many other organic materials, but its nitrogen and phosphoric acid cannot as a general rule be valued more highly than nitrogen in inorganic nitrogenous fertilizers or phosphate in superphosphate.

Dried Poultry Manure.

Poultry dung is a valuable manure provided it is protected from the weather until applied to the soil. Recent investigations into the possibilities of artificially drying fowl manure have indicated that a useful fertilizer may thus be prepared, but the process is only likely to be of interest to poultry farmers who do not desire to use the material on their own holdings. When the manure is to be used by the producer, it should be stored under cover until required for application, and if it is intended to apply it as a top-dressing it should be mixed with an equal amount of soil and spread out in thin layers to dry. Poultry manure in the ordinary state contains from 50 to 60 per cent. of water, and about 2 per cent. of nitrogen, 1·2 per cent. of phosphoric acid, and 0·6 per cent. of potash. The artificial drying process improves the analysis to about 4 to 4½ per cent. of nitrogen, 3 per cent. of phosphoric acid, and 1·3 per cent. of potash. The dried product is a light bulky powder which it is difficult to distribute evenly when applied alone. As a drier and conditioner for compound fertilizers it would probably prove most useful. Undried or fresh fowl manure should be applied some two or three weeks before planting vegetable crops.

Hoof and Horn Meal.

This product is variable in composition and in fineness of grinding, and on the latter largely depends its efficacy and value as a fertilizer. Under the Fertilizers and Feeding Stuffs Act of 1926 it is only necessary to state the amount of nitrogen in this material, hence the purchaser should satisfy himself that the sample offered is finely ground. The nitrogen content varies from 10 to 15 per cent., and some grades mixed with ground bone also contain up to 10 per cent. of insoluble phosphoric acid.

Hoof and horn meal should be valued and used in accordance with its analysis and fineness of grinding. It is largely used in glasshouse cultivation where there is a rapid decomposition of

organic materials, and conversion to forms the plant can utilize. In some districts it is favoured by market-gardeners as a top-dressing and in the seed-bed, especially for cabbages and similar 'green crops'.

Dried Blood.

This substance is a very valuable fertilizer, particularly under glasshouse conditions where its effects on plant growth may be as rapid as those of sulphate of ammonia. Only the amount of nitrogen is required to be stated by the vendor, and this is generally about 12 to 14 per cent. Blood also contains calcium, sodium, potassium, and phosphatic compounds in readily available form. The material should be dry and powdery, but unlike many of the other organic materials some samples do not keep very well. Dried blood should be used and valued on the basis of its nitrogen content, but the action of the material and the presence of various salts justifies a slightly higher allowance than market unit price for inorganic nitrogen. Dried blood, like hoof and horn meal, is largely used on high-class horticultural crops about the manuring of which there is not nearly such precise information available as for farm crops. It is a very suitable nitrogenous fertilizer for glasshouse tomatoes.

Fish Guano.

This material must be distinguished from fish waste or fish gyps which are obtainable near the coast and are valuable fertilizing materials where long haulage is not involved. Fish guano is manufactured from fish refuse, the oil being first extracted and the residue dried and ground. The amounts of nitrogen and phosphoric acid must be stated by the seller and the fish residue must not be mixed with any other material if sold as fish guano. Fish guano is variable in composition, but the usual limits are 6 to 10 per cent. of nitrogen and 5 to 9 per cent. of insoluble phosphoric acid, and the material should be valued solely on the current unit prices of nitrogen and phosphoric acid. There is little evidence to indicate that fish guano possesses any special virtue over other common forms of nitrogen and phosphoric acid. On the other hand, fish waste which is applied in large quantities and often contains much salt, is valuable for improving the texture of light soils in dry districts.

Shoddy.

Shoddy should be pure woollen waste, but it often includes other fibrous materials which may be associated with wool in the textile industries. It follows that the proportion of wool is very variable and some samples of shoddy are almost valueless for fertilizer use as they are largely composed of other fibres. Unfortunately, under the terms of the Fertilizers and Feeding Stuffs Act, 1926, the vendor is not compelled to give any statement as to the amount of nitrogen contained in shoddy. Nevertheless this product should never be purchased without analysis, since the nitrogen may vary from 3 to 15 per cent. The grades with low analysis are not worth buying, and the nitrogen in the high grades of shoddy should not be valued at much more than half the unit price of nitrogen in the common inorganic fertilizers. Shoddy is extremely slow in action, involves much labour in securing even distribution and incorporation in the soil, it may introduce weed seeds, and there is a possible, though remote, danger of introducing anthrax to the soil. It is occasionally used as a conditioner in mixed manures which are stated as having their nitrogen partly in organic form. Where it can be obtained cheaply, i.e. at less than standard unit prices on to the farm, it is a useful material for crops requiring the continuous but slow liberation of nitrogen over a long period.

Soot.

Soot usually contains 3 to 5 per cent. of nitrogen and is used chiefly by market-gardeners. The nitrogen is readily available, being present as sulphate of ammonia, and soot is also valuable as a deterrent to insect attacks. It also improves the texture of heavy soils, and by darkening the colour of the soil it makes the soil more absorbent of the sun's heat. Soot is costly to apply since this is invariably done by hand; it is most commonly used for top-dressing green vegetables and on seed-beds to discourage slugs. It is often applied at rates equivalent to 7 to 10 cwt. per acre of sulphate of ammonia.

Waste Cakes.

The residues of many vegetable products used in the seed-crushing industry are available for use as fertilizers. Such

materials must be valued on the basis of their analyses and their cost on to the farm, and when haulage and distribution are taken into account these products are not worth more than a few shillings per ton above unit values. They are slow in action, but when organic matter from other sources is unobtainable or costly the waste cakes may have more than ordinary value. Products of this group are rape-cake and castor-meal. They usually contain from 3 to 6 per cent. of nitrogen and smaller amounts of phosphoric acid and potash. Waste vegetable products should be applied early in the season in order that bacterial action may render the plant food available when needed by the crop. They are liable to encourage the development of moulds and fungi, and for this reason they should not be applied in large amounts on seed-beds.

Meat and Bone Meal.

This material is manufactured from slaughter-house offal and animal carcasses, the fat being extracted and the residue ground to a coarse meal. It commonly contains from 3 to 8 per cent. of nitrogen and 10 to 20 per cent. of insoluble phosphoric acid. It is very similar to fish guano.

Other Waste Materials.

Many other waste products are offered from time to time as fertilizers, but rarely are they worth much more than the cost of carting. Their manurial value is generally very small, but on very heavy or light soils they may be useful in improving the physical condition of the soil, though even for this purpose they are only worth consideration when they are delivered at a cost of a few shillings per ton on to the field. In this category may be placed most of the sewage sludges, damaged seed-cake, leather waste, cloth and carpet clippings, hop and brewery residues, destructor and ashpit refuse. Some town refuse contains a proportion of human excreta, and such material may have a value approximately equal to that of farmyard manure. Rarely, however, are these substances worth more than the cost of cartage in view of the present prices of fertilizers and the means of enriching the organic matter in the soil by crops grown on the farm.

CHAPTER IV

PHOSPHATIC FERTILIZERS

Ammonium Phosphate. Formulae: Monammonium phosphate, $NH_4H_2PO_4$. Diammonium phosphate, $(NH_4)_2HPO_4$.

The source and types of this material have already been dealt with in the previous chapter. Monammonium phosphate when pure contains 61·7 per cent. of phosphoric acid, but the commercial product contains 56·5 per cent. of P_2O_5 or 63 lb. of phosphoric acid per cwt. of monammonium phosphate. It is also sold mixed with ammonium sulphate to increase the proportion of nitrogen to phosphoric acid. The diammonium phosphate in the pure chemical contains 53·8 per cent. of phosphoric acid and is manufactured on the Continent and sold with a guarantee of 53·4 per cent. of P_2O_5, equivalent to about 60 lb. of phosphoric acid per cwt. of fertilizer. Ammo-phos is the American product of this type and is sold in two grades containing respectively 11 per cent. of nitrogen and 48 per cent. of phosphoric acid, and 16·5 per cent. of nitrogen and 20 per cent. of phosphoric acid. Another ammonium phosphate fertilizer is Leunaphos, which is a mixture of diammonium phosphate and ammonium sulphate, containing 20 per cent. of nitrogen and 20 per cent. of phosphoric acid.

Ammonium phosphates are the most soluble forms in which phosphoric acid is applied to the soil, the 'mono' salt being more soluble than diammonium phosphate. Both are white crystalline products, very similar in appearance to synthetic sulphate of ammonia. Ammonium phosphate fertilizers are also made in granular and in powdery forms. The phosphoric acid in these fertilizers is more easily soluble and probably more rapidly disseminated through the soil than the phosphoric acid in any other fertilizer. Despite the extreme solubility of ammonium phosphate there is little fear of any loss of the phosphoric acid by leaching, except possibly on coarse sands in districts of heavy rainfall.

In addition to their rapid action the ammonium phosphates are highly concentrated and serve as the basis for concentrated fertilizers which supply all three plant foods. The ammonia

they contain is responsible for their acidifying effect on the soil and their tendency to scorch foliage, points which have already been touched upon. The ammonium phosphates are not so liable to cake as other crystalline nitrogenous fertilizers and are easily transported and stored. In contradistinction to the other phosphatic fertilizers the ammonium phosphates contain no calcium, and on extremely acid soils this is a disadvantage and may make them less effective than the older fertilizers in which phosphoric acid is combined with calcium. On the other hand, on soils containing large reserves of lime the ammonium phosphates are likely to prove superior to other forms of phosphates. On the great majority of soils in this country there will be no practical difference between equal weights of phosphoric acid supplied as ammonium phosphate or as superphosphate.

Superphosphate. Monocalcic phosphate, $CaH_4(PO_4)_2$.

Superphosphate is essentially a mixture of monocalcic phosphate, dicalcic phosphate, and calcium sulphate, and is obtained by treating finely-ground rock phosphates with sulphuric acid to convert tricalcic phosphate to the monocalcic form which is soluble in water. Superphosphate must be sold in this country with a statement of the amount of phosphoric acid which is water-soluble, and this is usually either 14 or 16 per cent., equivalent respectively to about 15½ lb. and 18 lb. of water-soluble phosphoric acid per cwt. Occasionally superphosphates may be offered containing up to 18 or 20 per cent. water-soluble phosphoric acid. In purchasing superphosphate it should be valued solely on its content of water-soluble phosphoric acid; statements in regard to phosphates, &c., should be ignored. Superphosphate contains about 50 per cent. of calcium sulphate which acts as a drier and tends to maintain a good friable condition.

Superphosphate is a dry, powdery material which forms the basis of compound fertilizers. Mixed fertilizers made with ordinary supers are generally referred to as low-grade mixtures because they cannot contain such high percentages of nitrogen, phosphates, and potash as compound manures made with ammonium phosphate. Although sulphuric acid is used in its manufacture, superphosphate should contain no free acid (phosphoric) and should be in fine, dry condition. Excess of acid or

insufficient curing produces a sticky superphosphate, difficult to apply and to store, as the acid rots the bags. Fortunately there is seldom any ground for complaint in regard to the condition of superphosphate produced in this country.

After ammonium phosphate, superphosphate is the most soluble and rapid in action of the phosphatic fertilizers and is consequently widely used where availability and quick effect are important, i.e. in the establishment of seedlings. Although the phosphoric acid in superphosphate is soluble in water there is practically no loss from any soils, and on application to the soil it is converted to a less soluble form, which is, however, for the most part readily available to plants. Superphosphate does not tend to increase soil acidity and, in fact, it may ultimately add to the calcium content of the soil. When applied in drills it may cause a temporary localized acidity and it is possible that this may be a partial explanation of the common opinion that superphosphate does not tend to diminish 'finger-and-toe' on land subject to this disease. On clay soils which are very acid, superphosphate may not give results as good as those from an equal weight of phosphoric acid supplied in a high-soluble slag. Under such conditions the free lime in basic slag is of considerable value, whereas none of the calcium present in superphosphate is in the free-lime state. On practically all other types of soil the phosphoric acid in supers is likely to be more effective during the season of application than that in any types of slag, mineral phosphates, or bone manures. On the other hand, if phosphates applied in one season are intended to meet the requirements of two or three crops, the less soluble forms of phosphoric acid often give as good results as supers in the later years, particularly on acid soils. Such differences are, however, generally small when equal amounts of phosphoric acid are compared in the different fertilizers. The calcium sulphate in supers is of little importance or value on soils in this country although under arid conditions overseas it may be of much benefit.

In order to obtain a more concentrated superphosphate, phosphoric acid may be used in place of sulphuric acid in the treatment of rock phosphate. Superphosphates produced by such means are known as 'multiple', 'double', or 'triple' superphosphates and may contain up to 45 per cent. of soluble

phosphoric acid. Such concentrated superphosphates are not as yet manufactured in this country and their advantage of high concentration is provided by ammonium phosphate. Like the latter they tend to increase soil acidity.

Basic Slag.

This substance, a by-product from steel furnaces, is of complex composition and it is very probable that the phosphoric acid is present in several combinations. Consequently no certain formula can be given, but the phosphoric acid is combined chiefly with calcium. The amount of phosphoric acid in basic slags ranges up to 18 per cent., but it is seldom any slags are marketed which contain less than 10 per cent. of phosphoric acid. These figures are equivalent to about 20 and 11 lb. respectively of phosphoric acid per cwt. of slag.

The value of a slag depends almost entirely on the amount of phosphoric acid which is readily soluble, and on the fineness of grinding of the slag. Under the provisions of the Fertilizers and Feeding Stuffs Act of 1926 the sale of slag must be accompanied by a statement as to the amount of the article which will pass through a prescribed sieve. The sieve officially prescribed has approximately 90 meshes per linear inch, i.e. over 8,000 meshes per square inch, each hole of the sieve having a side 1/180 of an inch in length. The proportion of the material guaranteed to pass through the prescribed sieve should never be less than 80 per cent., and some manufacturers guarantee a higher proportion even through a 100-mesh sieve.

The Fertilizers and Feeding Stuffs Act does not compel the vendor to make any statement in regard to the solubility of the phosphoric acid in slag; all that is legally necessary is to state the total amount of phosphoric acid. Nevertheless the value of basic slag is closely related to the amount of phosphoric acid which is citric-soluble, and slag should never be purchased without securing dependable information as to its solubility in standard citric acid solution or some closely comparable solvent. A high-soluble slag should have 75 per cent. or more of its phosphoric acid soluble in citric acid solution.

The soluble phosphoric acid in slag has a value almost equal to that in supers, especially on acid soils and in districts of good rainfall, but on soils containing an abundance of lime the

comparison becomes less favourable to slag. The insoluble phosphoric acid in basic slag cannot for practical purposes be valued any higher than the phosphoric acid in ground mineral or rock phosphate.

Basic slag also contains calcium compounds—the oxide, carbonate, and silicate—which are available for the correction of soil acidity, but for this purpose basic slag is not so effective as an equal weight of calcium carbonate, and high-soluble slags reduce acidity more quickly than low-soluble slags.

Basic slag is easily handled and stored and retains its condition provided the bags are not allowed to become damp. Its extreme fineness often prevents regular distribution even with the best of fertilizer drills, but since it is usually applied at rates of 5 to 10 cwt. per acre, the effects of uneven application are not so apparent as with more concentrated fertilizers and with dressings which supply nitrogen and potash in addition to phosphates.

Mineral or Ground Rock Phosphate. Formula: $Ca_3(PO_4)_2$.[1]

The mineral tricalcic phosphate is mined in many parts of the world, the rock being ground to a fine powder for use as a fertilizer. In addition to calcium phosphate the rock contains carbonate and often sulphate and fluorides, with small percentages of iron, magnesium, silica, &c. The proportion of phosphoric acid in the rocks which are used directly as fertilizers varies from about 27 to 40 per cent., corresponding to from 30 to 45 lb. of phosphoric acid per cwt. of mineral phosphate.

The sale of ground rock phosphate must be accompanied by a statement as to the total amount of phosphoric acid, and proportion of the material passing through the prescribed sieve, i.e. a statement identical with that covering the sale of basic slag.

Finely-ground mineral phosphate is definitely slower in action than the phosphatic fertilizers already reviewed, and on soils containing plenty of lime, or on light soils in districts of low rainfall, rock phosphate very often fails to show any effect. The phosphoric acid in this fertilizer is in relatively insoluble form

[1] Rock phosphate is really a much more complex material than is represented by the formula $Ca_3(PO_4)_2$, but for ordinary practical purposes this simple formula will suffice.

and it would seem that its successful use is dependent on soil conditions conducive to rendering the phosphoric acid more soluble, i.e. acid soils and a plentiful supply of moisture. Under such circumstances, especially on heavy soils, ground rock phosphate gives its best results, which may be equally as good as those obtained from high-soluble basic slag. Under most conditions, however, mineral phosphate gives results inferior to high-soluble basic slag, but not inferior to those from the low-soluble slags.

Ground rock phosphate is rarely suitable where rapid action is required as, for example, in the establishment of seedlings. Under suitable soil conditions it is a valuable fertilizer for crops which will occupy the ground for a relatively long period, such as permanent grass or a clover ley, and also for crops of the turnip and cabbage family which are efficient users of phosphates.

The phosphoric acid in ground rock phosphates is practically never so effective and rapid in action as the phosphate in superphosphate, and only rarely is it so effective as high-soluble basic slag. Rock phosphate, however, is relatively cheap and in the circumstances indicated as suitable its use will be justified. In addition to giving its best results on lime-deficient soils, rock phosphate tends to correct acidity.

Ground rock phosphate is often mixed with superphosphate in order to produce a phosphatic fertilizer intermediate in action and in price. A very common mixture is equal parts of each, giving a material containing about 20 per cent. of phosphoric acid including 5 to 6 per cent. of water-soluble and 7 per cent. of citric-soluble phosphoric acid. Mixtures of this nature are very frequently marketed under trade names.

Many attempts are made to render the phosphoric acid in ground rock phosphate more soluble and by a less expensive method than treatment with sulphuric acid.

Colloidal Phosphate.

One such method is by extreme fineness of grinding and the product is termed 'colloidal' phosphate, but the description is more figment than fact. Many such materials are air-floated but often contain less than 10 per cent. of true colloidal material, and have obvious drawbacks in transportation and application

as fertilizers. Under experimental conditions there is some evidence to suggest that extreme fineness of grinding gives a better effect during the first season than ordinary grinding, but the differences are not large. Moreover, the 'colloidal' process is costly and unlikely to attain practical importance, especially in view of the great difficulty of applying such materials.

Calcined Phosphates.

Roasting ground rock phosphates with sulphur, silicates, sodium carbonate, &c., are other processes having as their object the conversion of the phosphoric acid to more soluble form. Such products are usually marketed under proprietary names, and information is often available in regard to the solubility of their phosphoric acid in citric acid or ammonium citrate solution. Not a great deal of information is available in regard to the efficiency of the phosphoric acid in these materials, but generally speaking it would appear to be nearly as effective as that in high-soluble basic slag.

Precipitated Phosphate.

Precipitated phosphate is a very pure form of dicalcium phosphate, i.e. free from the minor impurities such as iron, alumina, silica, which are present in fertilizers made direct from natural rock. Precipitated phosphate is usually prepared by leaching degreased bones with weak mineral acid to obtain a solution of monocalcium phosphate. From this solution precipitated phosphate is obtained by the addition of milk of lime. Dicalcium phosphate is citric-soluble and is therefore a readily available form of phosphoric acid for agricultural purposes, but the product is normally too costly for use as a fertilizer except on high-priced horticultural crops.

Bone Manures.

Bone materials have long been used as fertilizers and even to-day retain their popularity, although phosphoric acid may be purchased in cheaper and more efficient forms than in bones. Apart from guano and fish waste, bones are the only important source of phosphoric acid of organic origin, and despite the fact that such phosphoric acid is generally less effective than that in the various manufactured fertilizers derived from mineral phosphates, the old popularity of bones and their description

as organic manures is sufficient to ensure their ready sale at comparatively high prices. Bone meal and steamed bone flour are, however, useful in making fertilizer mixtures in that they assist in keeping the mixture open and friable and reduce the tendency to set and harden or to become sticky. Cheaper materials for this purpose are, however, more generally used by manufacturers.

Bone Meal.

In the preparation of this product the fat is removed, the bones then ground to a fine meal, but not nearly so fine as basic slag or ground mineral phosphate. Bone meal thus prepared contains nitrogenous compounds of which gelatin is the most important, and has an analysis approximating to 4 per cent. of nitrogen and 22 per cent. of phosphoric acid—all insoluble. These figures correspond to about $4\frac{1}{2}$ lb. of nitrogen and $24\frac{1}{2}$ lb. of phosphoric acid per cwt. of bone meal. The sale of bone meal must be accompanied by a statement of the amounts of nitrogen and phosphoric acid in the material. The nitrogen in bone meal cannot be valued any higher than the nitrogen in other artificial fertilizers, and the phosphoric acid is definitely of lower value than water-soluble phosphoric acid, but about 75 per cent. is citric-soluble. The phosphoric acid in bone meal is, therefore, more valuable than that in ground mineral phosphates under conditions favourable to rapid decomposition of organic matter in the soil, on light land in dry districts. In such circumstances bone meal may be valued at little less than equivalent amounts of sulphate of ammonia and superphosphate, provided a quick effect is not required.

Generally speaking, bone meal is slow in action and is used chiefly by market-gardeners and horticulturists who in the past have relied largely on slow-acting and foolproof organic manures. Despite the slow action of bone meal there is little evidence to suggest that its effects are appreciably more lasting than those of more readily available phosphatic fertilizers supplying equivalent amounts of P_2O_5.

Steamed Bone Flour.

In the production of this fertilizer the gelatin and other nitrogenous constituents are removed in addition to the fat, the

residue being ground to a fine, dry powder. Steamed bone flour thus contains very little nitrogen, only about 1 per cent., and for practical purposes is a purely phosphatic manure. Most samples contain from 25 to 30 per cent. of P_2O_5, equivalent to 28 to 33½ lb. of phosphoric acid per cwt. A statement as to the amounts of nitrogen and phosphoric acid in steamed bone flour must accompany each sale.

Apart from the nitrogen, steamed bone flour is very similar to bone meal, although the former is more finely ground and consequently the phosphoric acid may be more quickly available, but no practical distinction in this regard can be drawn. Steamed bone flour, owing to its dryness and fineness, is usually chosen as a 'drier' for incorporation in fertilizer mixtures made up on the farm.

Dissolved Bones.

This product is analogous to superphosphate, and is obtained by the treatment of ground bones with sulphuric acid to render the phosphoric acid more easily available for plant nutrition. Dissolved bone fertilizer usually contains about 2·5 per cent. of nitrogen and about 16 per cent. of P_2O_5. This is equivalent to 18 lb. of phosphoric acid per cwt., of which usually more than half is water-soluble. With the sale of dissolved bones the vendor must state the amounts of nitrogen, soluble phosphoric acid, and insoluble phosphoric acid. The soluble phosphoric acid may be valued on the basis of soluble P_2O_5 in superphosphate, the insoluble phosphoric acid and nitrogen on the basis of these substances in bone meal.

Bone Charcoal.

Bone char or bone black is obtained by burning bones out of contact with air. The product is used in refining raw sugar, and after this process the material becomes spent bone charcoal. It can be used as a phosphatic fertilizer and is obtainable in several degrees of fineness and with an average analysis of 34·5 per cent. P_2O_5, 46·4 per cent. CaO, and 10 per cent. carbon. Various grades are offered of which the following are typical:

1. Coarse dust—through 40-mesh sieve (0·016 in.), 75 per cent. $Ca_3P_2O_8$, or approximately 34 per cent. P_2O_5.
2. Fine dust—similar to above but finer comminution.

3. Spent bone charcoal—used material—very coarse, 85 per cent. $Ca_3P_2O_8$, or about 40 per cent. P_2O_5.
4. Grey bone charcoal—similar to (3) but mixed with flue deposits.
5. White bone charcoal obtained by burning off carbon from spent bone charcoal, about 40 per cent. P_2O_5.

Guano.

It has already been pointed out that the composition of guanos depends upon the amount of weathering they have undergone. A guano rich in phosphoric acid contains little nitrogen, but a guano containing little nitrogen is also likely to contain little material that is really in the organic condition although of organic origin. To comply with the conditions of the Fertilizers and Feeding Stuffs Act the sale of guano must be accompanied by a statement as to the amounts of nitrogen, total phosphoric acid and potash. The guanos containing little or no nitrogen have a phosphoric acid content of from about 20 to 30 per cent, P_2O_5, while the nitrogenous guanos contain from 10 to 20 per cent. P_2O_5. Both types of guano may also contain from 2 to 5 per cent. of potash.

The phosphoric acid in guanos, like that in other natural or organic materials, is not in water-soluble form and is slow in action. For this reason a high value cannot be placed upon it, but that in a nitrogenous guano is likely to act more quickly than the phosphoric acid in a weathered guano. For fertilizing purposes the former may be compared with bone meal and steamed bone flour, while the purely phosphatic guanos may be compared in regard to their phosphoric acid with ground mineral phosphates.

The guanos are little used in this country apart from horticulturists and by fertilizer manufacturers who desire to make a point of including organic manures in their mixed fertilizers.

The phosphoric acid in guano is present as tricalcic phosphate, identical with that in mineral or rock phosphate and in bones, and, like the latter materials, guano may be treated with sulphuric acid to convert the phosphoric acid to a more available form. Guano treated in this manner is termed 'dissolved' guano, and its water-soluble phosphoric acid is comparable with that in superphosphate.

CHAPTER V

POTASSIC FERTILIZERS

POTASH is present in large quantities in soils and rocks throughout the world, and also in sea water. Those rocks which have been commercially developed contain relatively high amounts of potash which can be economically extracted. The best-known deposits are those worked near Stassfurt in Germany and in Alsace, France, but potash is also mined in Poland, Russia, Spain, U.S.A., and undeveloped areas are located in other parts of the world. Potash is also extracted from lakes in dry, hot districts and is obtained from sea-weeds in the making of kelp.

Kainit.

This is the lowest-grade potash fertilizer and contains potash equivalent to 14 per cent. of potassium oxide, or K_2O, which is the conventional unit for stating the amount of potash in fertilizers. Kainit is of very variable composition but, as with all the potash fertilizers under the Fertilizers and Feeding Stuffs Act, 1926, it is only necessary for the vendor to state the amount of potash (K_2O). The potassium in kainit is present as potassium chloride, and other substances present are sodium chloride, magnesium sulphate, magnesium chloride, calcium sulphate, &c. One cwt. of kainit thus contains 16 lb. of potash (K_2O).

This fertilizer consists of variously coloured, coarse, and irregularly-shaped particles which easily take up moisture in damp surroundings. This property, however, seldom causes much difficulty in the transport and application of kainit but makes it unsuitable for farm mixing with other fertilizers unless the mixture is applied shortly after making up.

The effects of potash as a plant food have already been reviewed, but in considering the use of kainit the influences of the other substances in this fertilizer must be noted. Sodium chloride or common salt usually comprises at least half the weight of kainit. The sodium tends to make some of the soil potash more available to the plant. This is a valuable feature, but on a clay soil the sodium may result in the destruction of tilth, as previously noted. Consequently kainit should not be

chosen as the potash fertilizer on heavy arable soils unless they contain an abundance of lime. The chlorides present in kainit are likely to be beneficial to sugar-beet and mangolds but may be harmful for potatoes and fruit. Kainit appears to be best suited to the light soils—the sands and chalks.

Kainit is easily soluble in water and except on light soils there need be no fear of loss of potash in the drainage water, though the bulk of the other constituents may be leached away. This is an advantage since seedlings may suffer from the presence of some of the salts, and to avoid this it is desirable to apply kainit at least some three or four weeks before sowing the crop. Moreover, large applications on lime-deficient soils may result in a temporary increased acidity of the soil solution which may be harmful. Such acidity will be removed by the drainage water and is an additional reason for the early application of kainit. The ultimate effect of kainit on the soil acidity is practically nil.

Kainit, like all fertilizers with a strong tendency to absorb moisture, may scorch foliage severely, particularly that of young clover. Finely-ground kainit is, in fact, used in the same manner as cyanamide for the destruction of broad-leaved weeds in cereal crops. Where kainit is applied as a top-dressing care should be taken to see the foliage is dry during application, and especially is this important on young clover leys.

Potash Salts.

This product is marketed in several grades of which only two are common in this country: one containing 20 per cent. of K_2O, and the other 30 per cent. of K_2O, equivalent respectively to $22\frac{1}{2}$ lb. of potash and $33\frac{1}{2}$ lb. of potash per cwt. Potash salts are essentially mixtures of potassium chloride and sodium chloride, with small amounts of the other materials previously noted as present in kainit. Potash salts may be regarded as refined grades of kainit and in most respects intermediate between it and chloride of potash.

The 20 per cent. potash salt is sometimes described as sylvenite or extra kainit, and the 30 per cent. potash salts may also be termed sylvenite. In each case, however, the amount of potash in terms of K_2O must be stated by the vendor. On the Continent 25 and 40 per cent. potash salts are available in addition to those offered in Great Britain.

Potash salts are particularly valuable where heavy dressings of potash are not required and for circumstances where there is no strong objection to the sodium chloride they contain. At normal rates of application they can be applied up to the time of sowing, though an interval of several days is preferable.

Chloride of Potash. Formula: KCl.

This fertilizer, also known as muriate of potash, contains rather more than 80 per cent. of potassium chloride mixed with common salt. The potash (K_2O) is usually guaranteed at least 50 per cent.; thus 1 cwt. contains 56 lb. of potash. The crystals are usually white in colour, and the fertilizer is more easily stored than kainit or potash salts.

Muriate of potash is the most concentrated of the fertilizers which supply only potash, and grades are available containing up to 60 per cent. of potash. It is largely used in the mixing of fertilizers, and for farm-made mixtures the high concentration of potash in chloride of potash effects a big saving in labour over the lower-grade potash fertilizers. Mixtures made up with chloride of potash have a greater tendency to set than mixtures made with sulphate of potash.

Chloride of potash may be applied at any time, but particularly on soils in dry districts it is not suitable for crops which are intolerant of chlorides. In certain districts this objection may be of practical importance with potatoes; for glasshouse crops and fruit, sulphate of potash is usually preferred.

Sulphate of Potash. Formula: K_2SO_4.

This fertilizer contains from 90 to 95 per cent. of potassium sulphate and is usually guaranteed to contain the equivalent of 48 per cent. of K_2O, corresponding to about 55 lb. of potash per cwt. For practical purposes it may be regarded as supplying the same amount of potash as the common grade of chloride, but unlike the latter the sulphate contains only traces of the other materials present in the original kainit. The crystals are pellucid and hard, and practically unaffected by atmospheric conditions, consequently sulphate of potash presents no difficulties in transport, storage, or application. Sulphate of potash is made from the chloride and consequently is appreciably dearer than the latter, but for expensive and high-quality crops

the use of sulphate of potash is justifiable under conditions where chlorides may be harmful. It is also a most suitable source of potash for farm-made mixtures which may have to stand some time before they are applied.

Sulphate of Potash-Magnesia.

This is a mixture of sulphate of potash and sulphate of magnesium and contains 50 per cent. of the former, giving a K_2O content of about 25 per cent., equivalent to 28 lb. of K_2O per cwt. This fertilizer, though used in considerable amounts on the Continent, is practically unknown in this country, and there would seem no need for its introduction. The only possible scope would appear to be on magnesium-deficient soils cultivated for market-garden crops and fruit and receiving little farmyard manure. Even under these conditions magnesium could be more economically supplied by a dressing of magnesium limestone, and for other conditions where limestone would not be suitable magnesium could be supplied in kainit and potash salts.

Potassium Nitrate. Formula: KNO_3.

Reference has already been made to this fertilizer. It is sold in several grades with different proportions of nitrogen and potash, of which 15 per cent. nitrogen and 18 per cent. potash, 12 per cent. nitrogen and 40 per cent. potash are common examples; the commercially pure product contains 13·5 per cent. nitrogen and 44 per cent. potash. The use of this material is practically confined to market-gardeners and horticulturists who employ it as a top-dressing for high-quality crops. For such a purpose it is a useful fertilizer, rapid in action, giving a good colour to the plants, and the application of potash in conjunction with nitrogen offers a safeguard against the undesirable effects of nitrogen on land deficient in available potash. It is, in fact, a particularly suitable top-dressing for market-garden crops and for the type of soil usually adopted for this kind of cultivation. With price changes, however, potassium nitrate might become an expensive form of applying both nitrate nitrogen and potash, and a grower who understands the use of fertilizers should be able to supply the needs of his crops quite satisfactorily and more cheaply by the use of other fertilizers. Nitrate of potash maintains good condition better than other

nitrate fertilizers and hence is the most suitable for mixtures in which nitrate nitrogen is required.

Flue Dust.

This material is obtained from blast furnaces and may often be a relatively cheap source of potash, but before purchase a guarantee in regard to the potash content should be obtained. The percentage of potash may be anything up to 15 per cent., but it is not all in soluble form, but present chiefly as sulphate and silicate. Since flue dust may also contain small amounts of substances injurious to plants, the material is best applied some weeks before sowing or planting the crop. The colour of the product as collected from the flues gives an indication of its value. A light buff-coloured dust is usually richest in potash, the poorer grades shading down from dark red to greyish black. This product is an extremely fine powder, and anything approximating to even distribution can only be obtained when flue dust is applied with a drill during calm weather. Flue dust should not be mixed with fertilizers containing ammonia or with superphosphate, and, in fact, it cannot be satisfactorily used for mixing on the farm, and it is best applied by itself. The potash in flue dust cannot be valued so highly as the wholly soluble potash in the fertilizers previously described. Flue dust is likely to give its best results on acid soils.

Wood Ashes.

All growing plants contain potassium compounds, and the ashes of plants contain potash as potassium carbonate, often in relatively large amounts. Generally speaking, such ashes when fresh contain the equivalent of 5 to 15 per cent. of K_2O, but those of some plants contain a good deal more. The potash in wood ashes is easily soluble in water and is fixed in the colloidal portion of the soil in a similar manner to that of the other potash fertilizers. Wood ashes, however, also reduce soil acidity and in addition to potash they contain much lime. Wood ashes should be distributed in fresh condition since if they are exposed to rain the potash is easily leached away. It should be noted that coal ash contains very little potash, since this was dissolved and removed when the coal beds were being formed. Coal ashes are, however, often valuable for 'opening up' heavy soils where

the ashes can be obtained delivered on the field for practically no cost. Used in this manner their action is, of course, a purely physical one resulting in better aeration and water movement in the soil.

Kelp.

Many kinds of seaweeds contain high proportions of potash in addition to nitrogen and make useful fertilizer material on farms near the shore which have light soils and on which green manuring is too expensive. The fresh material is similar in composition to farmyard manure; dried seaweed contains from 2 to 4 per cent. of potash. There are few circumstances, however, where the hauling of fresh seaweed for manurial purposes can be justified, but the ash is not open to the same objection. Seaweed is dried by sun and air, then slowly burnt in shallow pits, and the residue is termed kelp. About 20 tons of wet seaweed are required for the production of one ton of kelp, which may contain 15 to 20 per cent. of K_2O in the form of potassium sulphate and potassium chloride. Kelp also contains various sodium and magnesium salts and iodine, and for fertilizer purposes may be regarded as very similar to kainit.

CHAPTER VI

MIXED AND COMPOUND MANURES; THE MIXING OF FERTILIZERS

Few of the fertilizers described in the previous section contain all the three plant foods, nitrogen, phosphoric acid, and potash, which it was earlier indicated must usually be applied to the soil if the maximum economic crops are to be obtained. Consequently, where these three plant foods are deemed necessary, several different fertilizers must be used, and in order to save the labour of separate applications two or more fertilizers are frequently mixed together and applied in one operation. It is true that farmyard manure and some other organic fertilizers contain nitrogen, phosphoric acid, and potash, but it is obvious that the same proportions of these plant foods will not be equally suitable for all crops and all soils. Many fen soils, for example, contain plenty of nitrogen while deficient in phosphates and potash for most crops, and some clay soils give little response to potash but are greatly lacking in phosphates. Sandy soils generally require good dressings of nitrogen and potash but relatively less phosphoric acid. Moreover, it is common knowledge that the various crops on the same soil generally require different manurial treatments.

Thus, in theory, fertilizer mixtures may be adjusted in respect of their proportions of nitrogen, phosphoric acid, and potash to conform to the requirements of different crops and soil conditions, in order that the needs of the crop may be fully met and wasteful expenditure avoided in supplying one plant food to excess in order to provide a sufficiency of another.

In addition to economy of labour in application the mixing of fertilizers has other advantages. It ensures that the plant foods are applied together and, provided the application is made at the right season, they are consequently all available to the plant at the same time. The crop is thus less likely to have an undesirable reaction to the manuring than if the different foods were given at separate intervals. Moreover, if the foods are available together, each is more likely to be used to the fullest advantage by the plant than under conditions where there is

a possibility of a deficiency of one of them; thus it is more probable that each plant food will give its best result when applied in conjunction with the others.

Fertilizers like sulphate of ammonia and chloride of potash are often only required at rates of from 1 to 2 cwt. per acre, and when applied separately it is difficult to secure anything like even and regular distribution in such small quantities. This drawback is overcome to some extent by using mixed fertilizers involving the application of several cwt. of material per acre, providing of course that the fertilizer mixture has been well prepared.

Mixed fertilizers, when obtained from a reliable source, may often be of considerable advantage to a farmer whose knowledge of manuring is limited. In such cases, and where expert advice is not obtained, it is without doubt the safest policy to depend largely upon mixed fertilizers, but, on the other hand, this course may not always be the best for the man who understands the use of fertilizers. The informed user should know the requirements of his soil, &c., better than the manufacturer.

When fertilizers are mixed together various interactions take place, some of which are undesirable since they result either in losses of plant foods or in a mixture whose physical condition is unsuitable for easy application and regular distribution. In other cases the interaction is entirely beneficial, improving the value of the original components for fertilizer purposes. Before the farmer can consider the mixing of fertilizers he must therefore know which fertilizers may be used together and what are their effects in mixtures. A few general rules may be given in regard to the chemical interactions resulting in losses of plant foods which may arise in the mixing of fertilizers.

Fertilizers containing nitrogen in the form of ammonia should never be mixed with fertilizers containing free lime, since loss of ammonia is inevitable and the effect of the lime in correcting soil acidity will generally be reduced. The farmer, in order to be perfectly safe, may also regard organic nitrogenous manures in this respect as similar to ammoniacal fertilizers. It is, however, safe to mix sulphate or chloride of ammonia with materials containing carbonate of lime, provided the mixed fertilizer is kept dry. Soluble carbonates, however, will set free ammonia, and mono-ammonium phosphate should not be mixed with

more than an equal weight of limestone if loss of ammonia is to be avoided.

Products containing nitrogen in the nitrate form should not be mixed with materials likely to contain free acid, e.g. badly made superphosphate, dissolved bones or dissolved guano, or acid sulphate of ammonia, since the free acid will cause loss of nitrogen.

Fertilizers containing water-soluble phosphoric acid when mixed with materials containing free lime or carbonate of lime may become less effective through the conversion of the soluble phosphoric acid to a less available form.

The physical effects of mixing the different fertilizers vary considerably, and even different samples of some fertilizer materials may not have identical properties when used in mixtures.

Sulphate of ammonia can normally be mixed with superphosphate, but if the mixture is left for some time it slowly begins to set or cake; unless some drying material is included, the mixture should be applied as soon as practicable. This tendency is hastened when potash manures are included in the mixture, kainit having most and sulphate of potash least effect.

Nitrate fertilizers when mixed with the lower-grade potash or water-soluble phosphoric acid fertilizers tend to produce fairly rapidly a soft and pasty mixture. This can to some extent be counteracted by including a drier, but all such mixtures should be applied within a short time of making up.

All soluble fertilizers will absorb moisture from the air, and the amounts absorbed may be increased when such soluble materials are mixed together. Thus a mixture of sulphate of ammonia, nitrate of soda, superphosphate, and potassium chloride will take up more moisture than the sum total of the amounts absorbed by the individual fertilizers.

The insoluble phosphatic fertilizers are used principally in fertilizer mixtures as drying agents. For this purpose steamed bone flour and bone meal are particularly valuable since they may be mixed with any fertilizer. Cyanamide, rock phosphate, basic slag, limestone, chalk, and gypsum have similar uses, subject to the limitations previously noted in regard to lime and carbonate of lime.

The organic fertilizer materials are highly esteemed in mixed fertilizers for their effect in keeping the mixture open in texture and in readily friable condition. The inclusion of organics is

most necessary when mixed fertilizers cannot be applied shortly after preparation and consequently organic materials are largely employed by 'the trade'. Fertilizer mixers also make use of a wide variety of materials as 'conditioners' and driers which in themselves have little or no fertilizer value, but they maintain the mixtures in good condition for use, which is of more importance than the production of a fertilizer mixture of higher analysis but which may give trouble through loss of condition after manufacture. It will be seen later that this difficulty has been surmounted by granulation and the production of true compound manures, i.e. fertilizers in which two or more of the plant foods are chemically combined with each other and not present merely as mechanical mixtures of substances containing only one plant food.

The mixing of fertilizers is a handicraft, and if the farmer considers it to his advantage to make up his own mixtures, he should as a rule mix shortly before application and include a proportion of one of the driers to secure a mixture which can be applied without difficulty. The table on page 79 will serve as a summary and guide to the mixing of fertilizers on the farm. The use of the table scarcely requires explanation; opposite each fertilizer is a row of symbols the meaning of which is indicated at the foot of the table. Each symbol refers to the mixture of the fertilizer in the particular row with the fertilizer in the particular column. Thus sulphate of ammonia may be mixed at any time with Nitro-Chalk or with sulphate of potash, but not with nitrate of lime or basic slag, and sulphate of ammonia should only be mixed shortly before use with urea or with ground rock phosphate. Some latitude must be allowed in the interpretation of the table since atmospheric conditions exercise an influence on fertilizer mixtures, and the table is not intended to apply to mixtures which may have to stand some weeks before application.

The hand-mixing of fertilizers involves other properties of the fertilizer materials besides those already considered. Some fertilizers are fine powders, others are in the form of small or relatively large crystals, while others again are granular or fibrous. When using such dissimilar materials it is very difficult to obtain a uniform mixture of the various ingredients, as with every movement the finer particles tend to become concentrated in the lower layers of the bulk. Moreover, even if a satisfactory

	Sulphate and chloride of ammonia.	Ammonium sulphate-nitrate.	Ammonium nitrate or Nitro-Chalk.	Sodium nitrate and potassium nitrate.	Nitrate of lime.	Calcium cyanamide.	Urea.	Guano.	Ammonium phosphate.	Superphosphate and dissolved bone.	Basic slag.	Rock or mineral phosphate.	Bone meal and steamed bone flour.	Kainit.	Potash salts.	Chloride of potash.	Sulphate of potash. Potassium magnesium sulphate.	Lime, oxide.	Lime, carbonate.	Animal manure.
Ammonium sulphate and chloride	Y	Y	Y	Y	N	N	I	Y	Y	Y	N	I	Y	Y	Y	Y	Y	N	I	Y
Ammonium sulphate-nitrate	Y	Y	Y	Y	N	N	N	N	I	I	N	I	Y	Y	Y	Y	Y	N	I	I
Ammonium nitrate or Nitro-Chalk	Y	Y	Y	Y	N	N	N	I	I	I	N	Y	Y	I	I	Y	Y	N	Y	I
Sodium nitrate and potassium nitrate	Y	Y	Y	Y	I	Y	N	Y	I	I	Y	Y	Y	Y	Y	Y	Y	Y	Y	I
Nitrate of lime	N	N	N	I	Y	I	N	N	N	N	I	I	I	I	I	I	I	I	I	I
Calcium cyanamide	N	N	N	Y	I	Y	I	N	N	N	Y	Y	Y	I	I	I	I	Y	Y	N
Urea	I	N	N	N	N	I	Y	I	I	N	Y	Y	Y	N	N	N	Y	I	I	Y
Guano	Y	N	I	Y	N	N	I	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y
Ammonium phosphate	Y	I	I	I	N	N	I	Y	Y	Y	N	I	I	I	I	Y	Y	N	I	I
Superphosphate and dissolved bones	Y	I	I	I	N	N	N	Y	Y	Y	N	I	I	Y	Y	Y	Y	N	N	I
Basic slag and processed rock phosphates	N	N	N	Y	I	Y	Y	N	N	N	Y	Y	Y	I	I	Y	Y	Y	Y	N
Ground rock or mineral phosphate	I	I	Y	Y	I	Y	Y	Y	I	I	Y	Y	Y	I	I	Y	Y	Y	Y	Y
Bone meal and steamed bone flour	Y	Y	Y	Y	I	Y	Y	Y	I	I	Y	Y	Y	I	I	Y	Y	Y	Y	Y
Kainit	Y	Y	I	Y	I	I	N	Y	I	Y	I	I	I	Y	Y	Y	Y	I	I	Y
Potash salts	Y	Y	I	Y	I	I	N	Y	I	Y	I	I	I	Y	Y	Y	Y	I	I	Y
Chloride of potash	Y	Y	Y	Y	I	I	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	I	I	Y
Sulphate of potash / Potassium magnesium sulphate	Y	Y	Y	Y	I	I	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lime, oxide	N	N	N	Y	I	Y	I	N	N	N	Y	Y	Y	I	I	I	Y	Y	Y	N
Lime, carbonate	I	I	Y	Y	I	Y	I	Y	I	N	Y	Y	Y	I	I	I	Y	Y	Y	N
Animal manure	Y	I	I	I	I	N	Y	Y	I	I	N	Y	Y	Y	Y	Y	Y	N	N	Y

Y = may be mixed at any time with little fear of depreciation of plant foods or in condition.
I = may be mixed shortly before use, i.e. within a day of application.
N = should never be mixed.

uniform mixture were obtained in the heap and immediately bagged, some separation of the various constituents will take place with the shaking in the fertilizer distributor so that there may be considerable variation in the product finally applied to the crop. The same feature continues to operate even after the fertilizer has left the drill hopper, since in windy weather the finer materials are carried by wind while the coarser particles drop immediately on the ground. This point is of even more importance when fertilizer mixtures are sown by hand; in the absence of wind the powdery material falls early in the cast and near to the sower, while the larger and heavier particles are thrown farther away, so that a separation of the various fertilizers occurs. This may often be the explanation of a patchy crop which is blamed upon the sower.

With the best will in the world the hand-mixing of fertilizers can never be so satisfactory as machine-mixing. In the latter process the different materials can be ground to approximately the same degree of fineness throughout, the modern mixing machinery secures a more intimate and efficient mixing than by hand, and the screening is more thorough than is usually possible under farm conditions. The machine-mixed product is thus more uniform, easier to sow, and there is considerably less danger of setting or loss of condition if the time of application has to be deferred through unsuitable weather. On the other hand, the commercially mixed fertilizers are usually less concentrated than the user would make himself, since the former contain materials included primarily as 'conditioners' and with little or no fertilizer value. While the home mixing of fertilizers can rarely give so satisfactory a product as that from an up-to-date fertilizer-mixing plant, the farmer has to decide what the convenience of mixing is worth to him, i.e. whether he should make his own mixtures or buy his fertilizers ready mixed. To this point we shall return later, but meantime a few notes may be given on the actual operation of mixing fertilizers on the farm.

In order to obtain a good mixture, a lumpy fertilizer should be broken down separately before being added to the mixing heap. Having decided upon the proportions of the different fertilizers to be included in the mixture and ensured their condition is satisfactory for the purpose, the ingredients with the coarsest particles should be spread in a layer of even thickness.

The depth of any layer should not be more than a few inches and its area should be convenient for easy and systematic working, i.e. spreading and turning of the fertilizers. On top of the first layer the next coarsest material will be evenly spread, and on top of this in turn the finer and more powdery ingredients. The weight of each fertilizer forming each separate layer will, of course, be strictly proportional to the weight of that ingredient desired in the final mixture. After all the component fertilizers have been added, the mixture will be turned thoroughly two or three times, working from one end of the heap to the other. After turning the mixture it should be thrown through a fine screen, and any remaining lumpy material broken down before bagging.

To determine the amounts of the individual fertilizers in cwt. required to make up a ton of a mixture of a given analysis, the desired percentage of any plant food in the final mixture is multiplied by 20 and the figure so obtained is divided by the percentage of that plant food in the straight fertilizer to be used. Thus, if a mixed fertilizer is required containing 4·5 per cent. of nitrogen, 6 per cent. of soluble phosphoric acid, 3 per cent. of insoluble phosphoric acid, and 5·3 per cent. of potash, the amounts of the individual fertilizers required in one ton of the mixture are obtained thus:

Nitrogen to be supplied by sulphate of ammonia (20·6 per cent. N).

Soluble P_2O_5 to be supplied by superphosphate (14 per cent. P_2O_5).

Insoluble P_2O_5 to be supplied by steamed bone flour (27 per cent. P_2O_5).

Potash to be supplied by 30 per cent. potash salts.

$$\frac{4\cdot5\times20}{20\cdot6} = \text{4 cwt. 40 lb. sulphate of ammonia.}$$

$$\frac{6\times20}{14} = \text{8 cwt. 64 lb. superphosphate.}$$

$$\frac{3\times20}{28} = \text{2 cwt. 16 lb. steamed bone flour.}$$

$$\frac{5\cdot3\times20}{30} = \text{3 cwt. 60 lb. potash salts (30 per cent.).}$$

Total weight 18 cwt. 68 lb.

It will thus be seen that by using these particular fertilizers for the mixture of the above analysis it would be necessary to add about $1\frac{1}{2}$ cwt. of some inert 'filler' to make up the ton. Alternatively if 20 per cent. potash salts were used in place of 30 per cent. the total weight of the ingredients would be 1 ton 42 lb., which would be sufficiently accurate for all practical purposes. It will be appreciated that in order to avoid the use of 'filler' materials the fertilizers selected for the mixture must be chosen on the lines of the analysis of the mixture. If the latter is high in nitrogen, a nitrogenous fertilizer of high analysis must be chosen, and if the mixture be low in potash, a low-grade potash fertilizer will be required, &c. Generally speaking, if the percentages of the three plant foods, nitrogen, phosphoric acid, and potash, in the required mixture when added together total more than about 22, the common fertilizers cannot be used unless the water-soluble phosphoric acid in the mixture is abnormally low. Hence in order to obtain high-analysis fertilizers, i.e. fertilizers containing more than 30 per cent. of these plant foods, it is necessary to use fertilizer materials such as ammonium phosphate and potassium nitrate in which two of the plant foods are chemically combined.

If it be desired to calculate the final analysis of a mixture of which the individual weights of the component fertilizers in one ton of the mixture are known, the opposite process to that described above is followed. The weight in cwt. of each fertilizer is multiplied by the percentage of the particular plant food it contains and the figure so obtained is divided by 20. If, for example, a mixture is to be made of $5\frac{1}{2}$ cwt. of calcium cyanamide, $1\frac{1}{4}$ cwt. nitrate of soda, 7 cwt. basic slag, $6\frac{1}{4}$ cwt. of kainit, its final analysis will be:

Calcium cyanamide $\frac{5\frac{1}{2} \times 20 \cdot 6}{20} = 5 \cdot 66$ per cent. nitrogen.

Nitrate of soda $\frac{1\frac{1}{4} \times 16}{20} = 1 \cdot 0$ per cent. nitrogen.

$6 \cdot 66$ per cent. total nitrogen.

Basic slag $\frac{7 \times 14}{20} = 4 \cdot 9$ per cent. insol. P_2O_5.

Kainit $\frac{6\frac{1}{4} \times 14}{20} = 4 \cdot 37$ per cent. potash (K_2O).

Concentrated Compound Fertilizers.

It has been pointed out above that if a mixed fertilizer of high analysis is required it is generally necessary to employ materials in which two of the three plant foods, nitrogen, phosphoric acid, and potash, are chemically combined. Fertilizers containing more than 30 per cent. of these three plant foods are often referred to as concentrated fertilizers to distinguish them from the relatively low-analysis mixtures in which the percentages of nitrogen, phosphoric acid, and potash do not total more than about 20. The concentrated fertilizers obviously make possible considerable economies in bagging, handling, storage, transport, and application, since a much smaller bulk of material is involved than in supplying the same amounts of plant foods in a low-analysis mixture. Actually the concentrated fertilizers can only be so termed because the description applies solely to the total amount of nitrogen, phosphoric acid, and potash they contain, and ignores calcium and other materials which are plant foods. They should not therefore be described as complete fertilizers; calcium especially is important as a plant food, but since it is chiefly used as a soil improver it is generally applied specially either as quicklime or carbonate of lime, and consequently it is usual to take little or no account of the calcium which may be applied in fertilizers and particularly in mixed fertilizers. For soils well provided with lime there is seldom need to consider that which may be applied in fertilizers, but on very acid soils the question becomes of much more importance. Since ammonium phosphate is the basis of the concentrated fertilizers they rarely contain an appreciable amount of calcium. Hence on soils seriously deficient in calcium the continued use of fertilizers containing none may lead to unsatisfactory results unless the land is also limed. It is also possible, though the circumstances are likely to be very rare, that light soils may respond to the sulphur in sulphates, and under such conditions ammonium phosphate would be less efficient than sulphate of ammonia and superphosphate, as the latter contains both calcium and sulphate. It is, of course, only under conditions that may be regarded as quite unusual that the ammonium phosphate type of fertilizer will be less effective than the calcium phosphate fertilizers, and in any event the most effective

means of dealing with such conditions is to apply lime in either the oxide or carbonate form. On the other hand, on soils containing an abundance of lime the ammonium phosphates are likely to act more effectively than the calcium phosphates, but on the great majority of soils there is little to choose between ammonium phosphate and water-soluble calcium phosphate.

The presence of small amounts of calcium, magnesium, and sulphur in mixed fertilizers intended for a wide variety of conditions is definitely a safeguard. These materials are, however, of much less importance than nitrogen, phosphoric acid, and potash, and consequently should never constitute a large part of the mixture, except of course where a mixed fertilizer is made up specially for a soil of known peculiarities. Thus a mixture containing either sulphate of ammonia or sulphate of potash will contain sufficient sulphate; if it also includes superphosphate it will contain an excess of sulphate and consequently be wasteful. For acid soils, unless lime is separately applied, mixed fertilizers containing lime should be preferred for crops susceptible to soil acidity. For this object magnesium limestone should be used as a 'conditioner' in the mixture; if mixed dry it will not drive off ammonia or seriously reduce the availability of the soluble phosphoric acid to the crop.

The concentrated fertilizers, however, are superior to the low-analysis complete mixtures in effecting easier mechanical distribution of the plant foods. As previously explained, the nitrogen, phosphoric acid, and potash in the low-analysis mixtures are derived from several materials, each supplying one plant food, and which are merely mechanically mixed together. The particles of the various materials always differ in size, weight, and shape, so that after mixing they tend to segregate with each movement of the fertilizer, which is likely to cause irregular distribution of the three plant foods. In the concentrated fertilizers the nitrogen, phosphoric acid, and potash are either in chemical combination or the materials are cemented together by special processes which prevent any alteration or reshuffling of the components, so that the three plant foods are applied in roughly identical proportions in every particle of fertilizer. Such concentrated fertilizers are made in granular form with the object of facilitating regular application. It may be, however, that concentrated mixed fertilizers will be marketed

in which ammonium phosphate and potash manures are merely mechanically mixed; such mixtures will be subject to the segregation of the component materials just as in the case of ordinary low-analysis mixtures.

Effect of Mixed Fertilizers on Soil Acidity.

It was explained earlier that certain fertilizers, particularly those containing ammoniacal nitrogen, result in an increased loss of lime from the soil, whereas other fertilizer materials add a small amount of lime or other base which serves to diminish acidity in the soil. Obviously the effects of such individual fertilizers will still be operative when they are added to the soil in mixtures with other fertilizers. Thus one or more components of a compound manure may tend to increase soil acidity while other constituents of the mixture may have the opposite effect. It is desirable that the sum total of the effects of the various ingredients should not increase soil acidity, at least on most soils and for the majority of crops. This object may be achieved by the incorporation of a small quantity of ground limestone as a drying and filling agent in the compound manure.

The acidity or basicity values of the different fertilizers used in making compounds may be expressed in terms of limestone, and a method has been proposed by W. H. Pierre[1] whereby the effects of the different components in a mixture can be calculated and the amount of limestone required to make the mixture non-acidifying can be determined. He gives the following figures of amounts of limestone in pounds required to correct the acidifying effect of 1 ton of the following fertilizers, and per unit of N in them:

	Per ton.	*Per unit of Nitrogen.*
Sulphate of Ammonia	2,349 lb.	107 lb.
Chloride of Ammonia	2,786 lb.	107 lb.
Urea	1,664 lb.	36 lb.
Ammonium nitrate	1,250 lb.	36 lb.
Peruvian guano	269 lb.	19 lb.
Dried blood	450 lb.	35 lb.
Fish scrap	169 lb.	18 lb.
Cotton-seed meal	190 lb.	29 lb.

In the same manner the amounts of limestone which are

[1] *American Fertilizer*, October 21st, 1933.

equivalent to 1 ton of the non-acidifying fertilizers have also been calculated as follows:

	Per ton.	*Per unit of Nitrogen.*
Cyanamide	1,245 lb.	57 lb.
Nitrate of Soda	583 lb.	36 lb.
Nitrate of Potash	515 lb.	40 lb.
Nitrate of Lime	407 lb.	27 lb.
Steamed Bone Flour	1,214 lb.	..

Organic materials are so variable that no constant value can be placed upon them, and the effect of such manures as superphosphates, mineral phosphate, sulphate and chloride of potash is negligible.

Thus by using these figures of the acidity or basicity in pounds of limestone of the ingredients in a compound manure it is easy to calculate the ultimate effect of the mixture. Thus a mixed fertilizer compounded from

	Acidity.	*Basicity.*
5 cwt. Sulphate of Ammonia	587 lb.	..
8 cwt. Superphosphate	..	..
4 cwt. Steamed Bone Flour	..	243 lb.
3 cwt. Chloride of Potash	..	..
	587 lb.	243 lb.

would require 587 lb. less 243 lb. of calcium carbonate, i.e. 344 lb., or 3 cwt. limestone per ton of mixture, to ensure that there was no increased loss of lime from the soil as a result of using this mixture.

Plant Food Ratios in Mixed Fertilizers.

Under the terms of the Fertilizers and Feeding Stuffs Act, 1926, the seller of a compound fertilizer must state the amounts of nitrogen, soluble phosphoric acid, insoluble phosphoric acid, and potash in the fertilizer. The percentages of these plant foods must be expressed as pure nitrogen (N), phosphoric anhydride (P_2O_5), and potassium oxide (K_2O). In the various forms of lime and chalk the calcium must be expressed as calcium oxide (CaO).

(*Note.* It is difficult to see any rational basis for the adoption of these conventions; nitrogen is usually present in fertilizers as ammonia (NH_3) or the radical NO_3, yet cannot be so expressed,

whereas potash is never present as the oxide in fertilizers, but the amount must be stated as the oxide. Moreover, calcium, which is often present in compound fertilizers in a form useful to plants, receives no recognition in this respect under the Fertilizers Act. A much more satisfactory system would be to state the amounts of the elements nitrogen, phosphorus, potassium, and calcium in all fertilizers, together with the particular forms in which they are present. Until such information is available, mixed and compound fertilizers can never be purchased or used with complete satisfaction. The purchaser can be certain he is not being imposed upon only if the whole of the ingredients and the sources of the plant foods in a fertilizer are declared.)

In addition to a statement of the percentages of nitrogen, phosphoric acid, and potash in a complete fertilizer, the plant foods are often also expressed in their equivalents of ammonia, sulphate of ammonia, phosphates, sulphate of potash. For the most part such equivalents may be completely disregarded and attention confined to the amounts of nitrogen, phosphoric acid, and potash. The equivalents are merely given in order to make the fertilizer appear of high analysis to the ignorant, and are calculated by multiplying the plant foods as follows:

The percentage of—
Nitrogen is multiplied by 1·2 to convert it to ammonia.
,, ,, ,, 4·8 to convert it to sulphate of ammonia.
Phosphoric acid is multiplied by 2·2 to convert it to phosphate.
Potash is multiplied by 1·8 to convert it to sulphate of potash.

After the amounts of nitrogen, phosphoric acid, potash, and calcium and the forms in which they are present, the next important point for consideration in a complete fertilizer is the ratio of the plant foods. Thus in a mixture of the following analysis: $\begin{matrix} N & P_2O_5 & K_2O \\ 5\% & 10\% & 5\% \end{matrix}$, the ratio of the three plant foods is 1:2:1. The proportions in which the three plant foods are required vary with different crops and soils and the use of mixtures which conform to ratios established for particular circumstances is commonly called 'balanced manuring'. The

production of all complete fertilizer mixtures should be based upon this principle and some twelve or fifteen different ratios would meet all the practical requirements of crops and soils in Great Britain where the three foods N.P.K. are involved.

At the present time there are far too many mixtures made, many of them differing in their plant-food ratios by very small amounts, and it cannot be too strongly emphasized that so far as the consumer is concerned there can never be any justification for such petty differences. From time to time slight adjustments may be convenient to the manufacturer, but such changes should be too small to affect the use of the fertilizer. A difference in the stated analysis of 2 to 3 per cent. of any plant food is too small to be of much practical significance in the rates at which fertilizers are normally applied. In the first place the Fertilizers and Feeding Stuffs Act permits variations in the analysis of from 0·3 to 1·5 per cent. of nitrogen, of 0·5 to over 2 per cent. of phosphoric acid, and of 0·3 to 2 per cent. of potash. Agricultural experiments are carried out with fertilizers which are rarely analysed, so that even the experimenter very seldom knows to within a few pounds per acre how much of the plant foods he has applied. Moreover, as pointed out earlier, the influence of the weather may be considerably greater than that of the fertilizer, so that the best mixture for a particular crop on a particular soil during one season may very likely not be the most suitable mixture for the same crop and soil during another season. Since it is not commercially practicable to manufacture mixed fertilizers with strict accuracy in regard to their analysis, and in view of the other considerations explained above, the number of mixtures recommended and used could be very much reduced with great benefit to manufacturers, merchants, and consumers, and incidentally to those connected in a technical capacity with all parties. The following list of ratios should amply provide for all crops and conditions in Great Britain where a fertilizer containing nitrogen, phosphoric acid, and potash is required. It will, of course, be appreciated that in some instances it will be desirable to supply the same N.P.K. ratio with different forms of N, P_2O_5, and K_2O. The sources of the plant foods should be chosen with regard to the type of soil and preferences of the crop where these are known.

Nitrogen. N.	*Phosphoric Acid.* P_2O_5.	*Potash.* K_2O.	
1	1	1	*
2	1	1	
3	1	1	
1	1	2	*
2	1	2	*
3	1	2	
1	1	3	
2	1	3	*
2	1	4	*
3	1	3	
1	2	1	*
1	2	2	*
1	2	3	*
1	3	1	
1	3	2	*
1	3	3	*
1	4	2	
1	4	4	*
2	2	1	
2	2	3	*
2	3	1	
2	3	2	
2	3	3	*
2	4	1	
2	4	3	
3	2	1	
3	2	2	
3	2	3	*
3	3	1	
3	3	2	

Those ratios which are starred in the above list would provide a sufficient range of N.P.K. fertilizers to meet practically all the circumstances in Great Britain where a complete fertilizer is required. Fertilizer dressings recommended later and which include two only of the N.P.K. trinity have the plant-food ratios shown in the table on page 90.

For soils known to be seriously deficient in lime, and where the farmer will not correct soil acidity by liming separately, then lime in some form should be included in fertilizers for crops which suffer from lack of lime in the soil. The foregoing N.P.K. ratios should be used as required, but lower percentages of these plant foods will be necessary in fertilizers for acid soils, since calcium, generally in the carbonate form, will also be incorporated. The minimum amount of calcium carbonate

Nitrogen.	*Phosphoric Acid.*	*Potash.*
1	1	
1	2	
1	3	
2	3	
1		1
	1	1
	1	2
	1	3
	2	1
	2	3
	3	2

in complete fertilizers for such circumstances will be that required to ensure that the fertilizer does not increase the drain upon the lime present in the soil. These minimum amounts can be calculated from the data given earlier in this chapter. The maximum limit to the amount of carbonate of lime equivalent in such a fertilizer mixture cannot be so readily decided, but it should not exceed one-third of the whole mixture.

CHAPTER VII

THE HANDLING AND STORAGE OF FERTILIZERS

ARTIFICIAL fertilizers are usually transported in vegetable-fibre sacks, which for some nitrogenous fertilizers may be lined with waterproofed paper or otherwise treated to protect the contents from atmospheric moisture. Nitrate of lime is frequently packed in moisture-proof wooden barrels, while at the other extreme kainit is not infrequently supplied loose in the railway truck. The type of packing adopted for the transport of any fertilizer naturally gives a good indication of its storage properties. Fertilizers which are supplied in moisture-proof containers should be opened only shortly before use in the field. All fertilizer materials should be protected from rain during transit, and on the farm until they are applied. The actual loss of plant food through rain damage to bags is likely to be very small with any fertilizer, but the material will absorb moisture and lose its free-running condition, and may set or become so pasty that it is difficult to sow and often can be applied only by hand. Bags which have become wet usually rot rapidly and even if they do not burst before the fertilizer is emptied they can rarely be used again.

The size of package is a fairly important consideration in so far as labour on the farm is concerned. The tendency during recent years has been to reduce the weight per bag, and although some fertilizers are still supplied in 2-cwt. bags, for many a 1-cwt. package is now adopted. The smaller weights naturally increase the cost of packing at works for both labour and materials, but the convenience on the farm amply justifies an extra charge. The 2-cwt. bag always involves handling by two people, particularly for emptying direct into the fertilizer drill, whereas the 1-cwt. bag can be handled by the average farm man without much difficulty. In fact, it will be found that the 2-cwt. fertilizer bag practically doubles the cost of man-labour in fertilizer application. It need scarcely be stated that fertilizer bags should never be handled with hooks or dropped from considerable heights, though a drop of 3 or 4 feet, followed by rolling the bag, is often effective in breaking up a slight setting of the contents.

The following are the weights of bags usually adopted for packing the various fertilizers:

2-cwt. sacks.

Sulphate of ammonia.
Nitrate of lime (100 kilos) (or casks).
Calcium cyanamide.
Bone meal.
Superphosphate.
Compound fertilizers.
Potash fertilizers.

1¼-*cwt. sacks.*

Basic slag.
Compound fertilizers.

1½-*cwt. sacks.*

Superphosphate.
Compound fertilizers.
Ground lime.
Urea (75 kilos).

1-*cwt. sacks.*

Nitro-Chalk.
Nitrate of soda.
Ammonium phosphate.
Ground lime.
Hydrated lime.
Concentrated fertilizers.

While, generally speaking, it is not desirable to store fertilizers on the farm for any length of time, it is not infrequently necessary to do so on account of field operations being delayed by weather. Moreover, price rebates are usually obtainable for purchases made before the heavy consuming season, and in any event the farmer should ensure delivery of his fertilizers in good time so that seeding operations will not be held up—he cannot reasonably expect to receive his fertilizers the day before he wishes to apply them. Consequently good storage conditions on the farm are necessary even though it should be the aim to use them only for relatively short periods.

Atmospheric humidity greatly influences the condition of fertilizers which take up moisture. Some fertilizers absorb moisture much more readily than others, and generally the more easily soluble the fertilizer the more quickly does it take up moisture. Organic manures, superphosphate (not freshly made), basic slag, ground mineral phosphates, sulphate of potash are scarcely affected by atmospheric moisture, whereas nitrate of lime, nitrate of soda, nitrate of ammonia, urea, and kainit absorb moisture very easily. The absorption of moisture results either in caking or in the fertilizer becoming pasty and sticky. The finer the particles of the fertilizer material, the more quickly are these changes brought about; hence large crystals or granules are advantageous for storage. Moreover, the mixing of powdery insoluble products, such as mineral phosphates or bone manures, with a very soluble fertilizer causes the crystals of the latter to become coated, so that there is much less danger of setting or stickiness.

Fertilizers should never be stored in buildings with damp walls or floors; a dry loft with a wooden floor is the most suitable

place. Where a wooden floor is not available a layer of some dry absorbent material, such as dry sand, straw, sawdust, or peat moss, should be laid down on which to pile the bags. The fertilizer store should never be an open shed but a place with well-fitted doors and windows, which may with advantage be opened during drying weather but otherwise should be kept closed. The object should be to maintain in the store the driest possible atmosphere and to prevent any changes in the amount of moisture in the air, since such fluctuations in humidity are the chief cause of the caking of many fertilizers. If it is possible to maintain a fairly dry atmosphere in the store the bags may with advantage be piled loosely, but if storage conditions are not good the bags should be regularly piled as closely together as possible and covered with empty sacks and a waterproof sheeting in order to prevent contact with moisture-laden air. With a high pile and consequently great pressure on the bottom bags, if setting does occur the lumps will be harder than in a small pile. Within the limits imposed by the labour of handling, the bags should be piled so as to obtain the least amount of surface exposed to the air, i.e. the pile should as nearly as possible conform to a cube. The following table indicates the relative storage properties of various fertilizer materials:

Materials which easily absorb moisture from the air and deteriorate in condition.	*Materials of intermediate character—only seriously affected in a damp atmosphere.*	*Materials practically unaffected by atmospheric moisture.*
Nitrate of lime.	Sulphate of ammonia.	Superphosphate.
Urea.	Cyanamide.	Basic slag.
Nitrate of soda.	Ammonium chloride.	Mineral phosphates.
Kainit.	Ammonium phosphate.	Bone manures.
Nitro-Chalk.	Chloride of potash.	Organic manures.
	Potash salts.	Sulphate of potash.
	Nitrate of potash.	
Lump lime.	Hydrated lime.	Ground limestone.
Small lime.		Ground chalk.
Ground lime.		

CHAPTER VIII

THE APPLICATION OF FERTILIZERS

THE object of fertilizer distribution is to ensure that the plants derive the maximum benefit from the fertilizer applied; the plant foods should be given in the amounts and the manner and at the time calculated to produce the most profitable effect. The application of fertilizers is perhaps the most important factor in their use since in practically all circumstances the beneficial or undesirable results on crop plants from the use of fertilizers are governed by the manner or time of application. All fertilizers properly used should give good results, but the choice of a fertilizer will naturally depend on other considerations than the manner in which it is to be applied. The question of application arises only after the nature and amounts of the plant foods to be given have been decided.

Regularity of Distribution.

Poor results from fertilizers which are attributable to the manner of their application are frequently due to actual damage either to seedlings or to scorching of foliage, but the effects of irregular distribution, while not so apparent, are also of great importance. Plants absorb their mineral nutrients from the soil solution in which the plant foods applied in fertilizers ultimately become dissolved. It has long been recognized that there is very little lateral or sideways movement of the soil solution or of the substances dissolved in it, or at any rate if such movement does take place at all it is extremely slow and in relation to the average growing period of agricultural crops it is practically non-existent. The grounds for this statement may be seen on nearly every farm, where the effect of a fertilizer often may be traced almost to an inch and exactly corresponding to the line where the fertilizer was applied. On agricultural experimental stations where plots have received the same fertilizer dressing annually for many years there is no evidence to indicate that the effects of the fertilizer have any spread beyond the original boundaries of a plot. Consequently regular distribution of fertilizers throughout the root zone should be the object in applica-

tion and irrespective of the type of fertilizer applied, i.e. whether soluble or insoluble, and supplying one or more plant foods. While the means of application employed have obviously great influence on evenness of distribution, the condition of the fertilizer material is itself of first importance.

Condition of Fertilizer.

While an enormous amount of investigation into the effects of fertilizers is undertaken throughout the world, it is curious that so little attention has so far been given to problems connected with fertilizer application. The few investigations which have been made into the effect of the physical condition of the fertilizer on distribution agree in indicating the superiority of granular fertilizers. To secure regular distribution by drill or by hand the particles of a fertilizer should all be identical in size, shape, and weight; the ideal fertilizer would consist of spherical particles about the size of shot-gun pellets. They should be sufficiently heavy to prevent their being carried by the wind and hard enough to withstand handling and to retain their shape without breaking into pieces before reaching the soil, but the particles should readily become dissolved by the soil moisture.

Fertilizers are now manufactured in granular form, and although such fertilizers represent a big step forward in ease of application from the old powdery or finely crystalline fertilizers, there is still room for much improvement in the evenness in size and shape of the granules in many granular fertilizers. The greater the irregularities in size and shape of the particles, the less likely is distribution to be even, and fertilizer materials may be classified roughly in the following order from the standpoint of promoting regular application: granular fertilizers, coarsely crystalline fertilizers, fertilizers consisting of mixed fine and coarse particles, fine powdery material.

It should be noted that this classification refers to the free-running nature of the materials, and does not necessarily apply to the even distribution of the three plant foods in a mixed fertilizer. Where the latter is composed of several materials, each having particles dissimilar to those of the other components, even distribution of the three plant foods cannot be expected. The components must therefore be reduced by grinding

to a powder or alternatively be combined together physically or chemically. The latter methods are more satisfactory since even in a powder there may be some segregation of the constituents before reaching the soil and there can be no guarantee that each plant receives approximately the same amounts of the plant foods in the same proportions. Powdery materials, in addition to being the least satisfactory products in actual application, are also the most subject to displacement by wind and surface-water, these two factors tending further to increase irregularities in distribution. These drawbacks are, however, of less importance than the increased rapidity of action secured by the fine grinding of the relatively insoluble fertilizer materials such as basic slag, bone manures, and mineral phosphates. Furthermore, if a powdery material can be evenly applied it can obviously then be more intimately mixed with the soil than is possible with a fertilizer of large-particle size.

Harmful Effects of Fertilizers.

Very small particles are a drawback when applying easily soluble fertilizers as top-dressings on growing crops, since the finer the particles the more easily do they adhere to the foliage and cause scorching. Scorching is chiefly due to the abstraction of moisture from the sap of the plant, causing the leaf tissues to wither and die, and its effects are most pronounced during rapid 'drying' weather. Scorching most frequently arises during spring when night frosts are followed by 'drying' winds, and later in the season when heavy dews are followed by hot sunny days. In both cases the foliage is damp when the fertilizer is broadcast and consequently much of it sticks to the leaves. The rapid drying wind or sun, as the case may be, follows and results in scorching; there is little fear of any such effect if the fertilizer application is immediately followed by rain. If the foliage is dry when the fertilizer is applied there is much less danger of the material adhering to the leaves, and it need scarcely be said that the larger the fertilizer particles the less likely are they to cause scorching. From this point of view the granular fertilizers are particularly valuable, since there is small likelihood of the granules remaining on the foliage.

Crops may also suffer from the effects of fertilizer in the soil, though damage of this nature is usually experienced only with

germinating seeds or seedlings. Bad germination usually results when seeds are sown in contact with soluble fertilizers, and the smaller the seeds the greater is the adverse effect. Large seeds, such as those of the cereals, are not easily damaged, and since rates of application of fertilizers to grain crops are relatively moderate, the seed and fertilizer may usually be sown together without harmful consequences. The deleterious effects of fertilizers on germination are most pronounced when the fertilizer is applied in rows and when the seed is sown at the same time in direct contact with the fertilizer. The danger is lessened when the seeds are sown a few days after the fertilizers, and small seeds should be sown slightly to the side where the fertilizer has been applied in rows. The best method of fertilizer application to minimize danger to seedlings is to apply the fertilizer a week or two before seeding and to mix it thoroughly with the soil throughout the zone where roots are likely to be most numerous. Some fertilizer must be within call of the plant in the early stages of development, but the tender seedling must not be poisoned by a surfeit.

The nature and condition of the soil influence the harmful effects of fertilizers on seedlings. The more soil moisture available the less chance there is of injurious effect, and the colloidal matter of the soil exerts a similar beneficial influence, so that injury from fertilizers is most likely to arise on light soils and during dry weather. Moreover, the bad effects of fertilizers on seedlings are most likely to be experienced on soils which are deficient in lime; this applies particularly where fertilizers are used which are wholly soluble and contain little or no calcium.

It would thus appear that the injurious effect of fertilizers on seed germination and seedlings is most likely to occur on light soils where moisture or calcium is deficient, where the seeds are small and sown about the time of fertilizer application. All the soluble nitrogenous and potassic fertilizers may have a harmful effect under some or all of the foregoing circumstances, but ammoniacal fertilizers are likely to be most harmful in this respect on soils seriously lacking in lime. It must not be thought that the three plant foods alone have this injurious action, since damage may be caused by any easily soluble substance which is present in sufficient concentration in the vicinity of the seeds. Hence a smaller weight of a concentrated fertilizer is likely to

be less harmful than the larger application of a soluble low-grade fertilizer which is required to supply an equal amount of the plant foods. Some substances are definitely more injurious than others, and some fertilizer materials contain, or produce in the soil, products which are particularly inimical to seedlings. It is for this reason that it is specially important to apply kainit, low-grade potash salts, and calcium cyanamide some time before seeding.

Damage may also arise from an application of an ammoniacal fertilizer shortly after liming while there is still much free lime in the surface soil. After an application of lime to ground under crop, ammoniacal fertilizers should be withheld until the lime has been thoroughly worked into the soil or until the latter contains plenty of moisture; a period of two or three weeks is usually quite safe.

Methods of Application.

Fertilizer application involves labour no matter what method be adopted, and anything which reduces labour costs is important. Attention has already been drawn to the influence of the physical condition of fertilizers on regularity of application, and this naturally bears closely upon labour costs; the better the condition of the fertilizer the less labour is involved in securing satisfactory distribution. The analysis of a fertilizer is, however, the most important factor affecting costs of application. Other things being equal, it is obvious that to supply a certain quantity of plant foods per acre in a fertilizer of high analysis involves less labour than the application of the same quantity of plant foods in a low-analysis fertilizer. A fertilizer containing, for example, 10 per cent. nitrogen, 15 per cent. phosphoric acid, and 15 per cent. potash requires only about a third of the labour required to apply a fertilizer analysing 3·3 per cent. nitrogen, 5 per cent. phosphoric acid, and 5 per cent. potash. It is of course true that the majority of fertilizer drills will sow 10 cwt. per acre as easily as 3 cwt., but the former dressing involves three times the amount of work and more frequent stoppages than the smaller dressing. Thus the concentrated fertilizer economizes labour and time which are always important but especially during the busy spring season.

Precautions to avoid the excessive application of concentrated

fertilizers are required where they are to be applied for the first time by men conversant only with low-analysis materials and using drills designed primarily for the latter type of fertilizer. It is the general experience of farmers that close supervision is necessary to safeguard against the universal tendency to sow fertilizers at higher rates than those recommended. This danger is greatly enhanced with concentrated fertilizers, and excessive applications of these products would be more costly than in the case of low-analysis fertilizers. Many of the older types of fertilizer drills cannot be relied upon to give even distribution where small quantities of the order of 2 to 3 cwt. per acre are to be applied. Consequently, if the full benefits from high-analysis fertilizers are to be obtained, an efficient and accurate distributor is a first essential. Such a machine should be capable of giving even distribution both along and across its track and of being accurately regulated to sow quantities down to 1 cwt. per acre. No matter how efficient the distributor available, the maker's calibration scale can only be taken as a general guide to the 'setting'. The machine may be designed to eliminate the variations in delivery rate arising from ground irregularities, slope of surface, speed of travel, amount of material in the hopper, &c., but the same 'setting' cannot be expected to deliver the same weight of fertilizers which vary widely in condition. However, great accuracy in the quantity sown per acre is not nearly so important as even and regular distribution both along and across the track of the machine.

A good fertilizer distributor gives more even distribution than can be obtained by hand either in broadcast or row application. The finer the fertilizer, the less satisfactory are the results from hand sowing, but granular or coarsely crystalline fertilizers may be conveniently broadcast by hand where the dressing to be applied is from 1 to 3 cwt. per acre. Hand-broadcasting should be confined to grassland, cereals, or uncropped land, since by this method much of the fertilizer falls upon the leaves and is likely to cause scorching if it lodges on the foliage. The broad-leaved crops are generally grown in rows and under this method of cultivation the fertilizer should be applied along the rows and so as not to fall on the foliage. Most fertilizer distributors can be easily adjusted for application to row crops, and should give at least as satisfactory results as hand dressing along the rows.

Top-dressings to row crops are frequently applied during dry weather when the surface soil is almost devoid of moisture. To secure rapid action it is desirable to get the fertilizer in contact with the soil moisture either by direct placement below the soil surface or by subsequent inter-row cultivation.

Hand application of fertilizers is usually inferior to mechanical distribution; it is also more unpleasant and may, in fact, involve risk to the sower. In this respect both nitrate of lime and calcium cyanamide may be dangerous, and wherever possible they should be applied by machine. These two fertilizers may also burn the clothing, and the skin should always be protected by a coat of oil or grease. It is always unwise to sow any fertilizers by hand if the skin be cut or broken.

Where fertilizers are applied for row crops shortly before seeding, precautions should be taken to prevent a high fertilizer concentration in the immediate vicinity of the seedlings. If the land is to be ridged, the most satisfactory method is to broadcast the fertilizer either before ridging or on the first-made ridges, and when the latter are split back the fertilizer becomes mixed with soil and placed in the central portion of the final ridge. Where the fertilizers are sown in the furrow they naturally remain in a restricted narrow band where the concentration may be harmful, and such conditions are also less likely to encourage wide root range than in the former method of application.

Although cereals and similar relatively large seeds may be sown together with fertilizers, it is always dangerous to adopt this practice with smaller seeds. The latter should not come into direct contact with soluble fertilizers, otherwise germination is bound to be seriously affected. Even with cereals and the larger seeds there is little doubt that germination may suffer to some extent when seed and fertilizers are applied together; but the damage is seldom serious, and when such plants have brairded their early development is often superior to that of plants for which the fertilizer has been broadcast before seeding. Moreover, the application of seed and fertilizer in one operation can obviously be made less costly than where the two are sown separately.

Fertilizers are rarely given in solution and then only under glass-house or garden cultivation where large quantities of water

can be easily applied. This method of supplying the plant foods is not only the safest but is also likely to ensure their most rapid effect upon the plant. There is little possibility of any loss of plant foods until the soil becomes so completely soaked that the drains begin to run; even on watercress beds, where the water is constantly flowing, the boundaries of an area to which soluble fertilizers have been applied may remain almost as clearly defined as under field conditions. For valuable glass-house and garden plants and for lawns, the solution method is the safest means of applying soluble inorganic fertilizers, and under such circumstances the extra labour involved is, of course, rarely an item of much moment.

Time of Application.

The time of application of fertilizers to a crop has much influence upon their effect and is often equally as important as the amounts and form of the plant foods supplied. The effect of a plant food which is desirable at one stage in the growth of a crop may be very undesirable at an earlier or later stage of growth. The availability of the plant foods to be applied has to be considered in relation to the time when their effect on the crop is required. Where rapid action is the object the plant foods must be given in water-soluble form at the time, or immediately before, such effect is wanted. On the other hand, where a relatively steady and sustained effect from the fertilizer is required the latter may be applied at any convenient time in spring before the onset of growth.

Of the four plant foods, nitrogen, phosphoric acid, potash, and calcium, the first calls for the exercise of most judgement in regard to time of application. Where a highly soluble nitrogenous fertilizer is applied, its effect may be seen under favourable circumstances within two or three days. Since the nitrate form of nitrogen is so rapid in action, and also since on some soils it may be leached from the root zone by heavy rain, it is invariably applied only at the time its effect on the plant is required. Consequently nitrate nitrogen should rarely, if ever, be given to any but growing plants; under very dry soil and weather conditions nitrate nitrogen may be applied at the time of sowing, but even under these circumstances it is usually cheaper to use ammoniacal nitrogen. Since all forms of nitrogen

applied to the soil may ultimately be converted to the nitrate form and thus become susceptible to leaching, it is generally undesirable to apply nitrogen for any crop much in advance of the growing season. This statement does not conflict with the recognized advantage of autumn applications of farmyard manure in dry districts. Under these conditions the benefits arising from such applications are due to the physical action of the organic residues of the dung and to their moisture-holding effects, these features outweighing the heavier losses of nitrogen incurred by autumn as against spring application. On the other hand, in districts of heavy rainfall, spring application of farmyard manure is preferable to an autumn dressing since the loss of plant foods is minimized, but on heavy arable soils in districts of high rainfall the incorporation of fresh farmyard manure in autumn helps to keep the soil more open and thereby promotes better aeration and drainage. Hence the nature of the soil and climate will determine the most suitable time of application of farmyard manure in so far as its effect upon the crop is concerned, but naturally this is only one factor which the farmer has to take into account in deciding upon the most economical method of disposing of this live stock by-product. Apart from the foregoing considerations, organic nitrogenous manures should be applied in early spring during the preparation of the seed-bed, and for perennial plants organic fertilizers should be incorporated with the soil during spring cultivations.

For certain root crops, carrots and sugar-beet, &c., where farmyard manure is deemed necessary it is best applied during the autumn previous to seeding, since spring applications usually cause an increased proportion of fangy roots.

No general rule can be followed in regard to the best time of application of the inorganic forms of nitrogen. The effect of nitrogen is chiefly manifest in the development of the foliage, and hence nitrogen should be given when it is desired to encourage the growth of the vegetative portion of the plant. Too much foliage, or a too prolonged development of it, is often disadvantageous, e.g. in cereals, potatoes, sugar-beet, peas, beans, and fruit, but there can rarely be too much healthy foliage with grass, fodder, and other crops grown for the green leaf. It by no means follows that for the former group all the nitrogen should be given early and that relatively late dressings should

be confined to the latter group. For winter-sown wheat, provided the braird is healthy, the application of nitrogen is generally best delayed until tillering is over, i.e. in late April or early May, depending on the crop, time of sowing, and the season. With sugar-beet the best results are usually obtained by giving all the nitrogen in the seed-bed, although if the crop receives a check it is desirable to apply a quick-acting nitrate fertilizer after singling. Moreover, where conditions make germination unreliable and the possible need for re-seeding cannot be disregarded, then a sound policy is to give only part of the nitrogen in the seed-bed and reserve the remainder for top-dressing or for the second seed-bed should this become necessary. The whole of the nitrogen for maincrop potatoes should be applied at or immediately before planting, since not only does this induce the biggest yield but, as with sugar-beet, the late application of nitrogen may delay ripening.

On grassland the time of application of nitrogen during the growing season has great influence on the period of foliage development although it may make little difference to the total yield of herbage over the whole season. A large dressing of nitrogen in early spring induces growth of herbage early in the season with a relatively large falling off later, whereas the same amount of nitrogen given in two or three dressings during spring and summer maintains a steadier production of herbage and approximately the same total yield for the season.

The application of nitrogen to market-garden crops which occupy the ground for many months is usually made in several dressings, although there is no experimental evidence that this method gives the highest yields. With these crops, however, the quality of the foliage is of as much importance as the quantity, and several dressings provide the grower with more control over the development of the crop and enable him to regulate the amounts of fertilizer and times of application to better advantage.

The effects of nitrogen in relation to the time of application would appear to be much more important than those of potash and phosphoric acid. The most suitable time of application for the various phosphatic fertilizers is naturally closely associated with the solubility of the phosphoric acid. The relatively insoluble phosphatic fertilizers, such as bones, low-soluble slags,

and mineral phosphates, may be applied at any convenient time during the year. Rarely are circumstances such that these manures have much influence upon the crop during the year of their application when used in normal amounts. On acid soils in districts of good rainfall, crops which are efficient users of phosphates may derive benefit from early spring applications of the insoluble phosphatic fertilizers, but as a general rule these manures should only be used where the object is to apply phosphates which will be slowly and steadily available over a period of three or four years. The quick-acting phosphatic fertilizers, ammonium phosphate, superphosphate, and, to a lesser degree, high-soluble basic slag, should be applied shortly before their effect upon the plant is required. The most important effect of phosphatic fertilizers is that of encouraging the early development and establishment of young seedlings, and for this purpose the soluble phosphatic fertilizers should be applied shortly before seeding. Moreover, the bulk of the phosphatic requirements of annual plants is taken up in the early stages of growth and is an additional reason for the spring application of quickly available phosphatic fertilizers. If such fertilizers are applied some months before the crop is likely to need them, there is a danger that the soluble phosphoric acid may either be leached from the seedling root zone on open, sandy soils, or changed in the soil to a much less available form. Consequently it is a safe general rule to apply soluble phosphoric acid fertilizers about the time of putting in the crop.

Since the potash in fertilizers is completely soluble in water, there is no advantage to be gained from its application before the crop is likely to be able to use it. In fact, there is the possibility that the longer the potash lies in the soil the less available to plants is it likely to become. On the other hand, little is known of the times when crops take up their major requirements of potash and at what stage of growth they make their biggest demand on the potash supplies in the soil. Moreover, the lower-grade potash fertilizers contain considerable amounts of chlorides, &c., which are known to be inimical to plant growth and which it is desirable to remove from the root zone before they can affect the crop. For this reason it is usual to apply the lower-grade potassic fertilizers some weeks before the crop is planted in order that the injurious substances may

be leached from the surface soil. This caution does not apply to the sulphate and muriate of potash, and these fertilizers may usually be applied safely at the time of seeding. Potash fertilizers are generally given in spring during the preparation of the seed-bed, but under some conditions it is possible that later application might give better results. Until definite evidence is available on this point, however, potash should be applied before planting the crop or in the 'dead season' to perennials.

The most suitable times for the application of lime are prescribed by cultural operations and weather conditions. Since the even distribution of lime and its thorough incorporation in the surface soil are of prime importance, dry weather and soil are necessary. Moreover, the deep annual cultivations should be completed before lime is applied, as it is easily washed down from the surface soil. The form in which lime is given also governs the time of application; the non-caustic forms will not damage the crop, but quicklime may seriously check growth. Burnt, lump lime is therefore best put on the land during winter or early spring after all ploughing has been completed. Ground quicklime may be applied to the seed-bed a few days before sowing, since it rapidly becomes slaked. Should the surface soil be very dry, ground lime should be harrowed in a week or two before seeding and it should not be applied at the same time as fertilizers containing ammonia; these should be withheld until the lime has become slaked and incorporated with the soil. Ground limestone and ground chalk may be given at any time, but are generally most conveniently worked into the seed-bed during spring cultivations. Lump chalk must be dealt with like lump lime since the shattering effects of winter frosts are necessary to secure even distribution by subsequent harrowings.

The foregoing considerations refer only to the season of the year during which lime may best be given, but an application of lime is generally expected to suffice for several years and consequently will influence the different crops grown during those years. The susceptibility to lime shortage of various crops has already been discussed, and lime should be given during the cropping sequence for the crop or crops whose need of it is greatest. In the most common rotations lime should be applied for crops of the turnip and cabbage family and for sugar-beet. The successful cultivation of these root crops demands no

shortage of lime in the soil, and since barley and clovers are generally the crops next taken and also require a soil with no serious lime deficiency, application during preparations for the root crop is the most suitable time in the rotation. The lime applied to the root seed-bed becomes thoroughly mixed with the surface soil during subsequent harrowing and hoeing, and the shallow ploughing for the following barley crop ensures the lime being kept in the surface soil for the clover seedlings. Lime cannot always be applied with safety for potatoes. The potato crop is tolerant of fairly acid soil conditions, although increased yields are not infrequently obtained after liming. The Common Scab disease of potatoes is encouraged by liming and consequently, unless the land is definitely known to be free from scab disease, liming should not be carried out immediately preceding the potato crop.

On grassland, lime is best applied during dry weather in winter or early spring, when the fields are bare of herbage and the lime can consequently be harrowed into the surface soil. If quicklime is to be used it should be applied before spring, otherwise the early development of grass may be checked.

Market-gardeners often apply lime for protection against slugs, and for this purpose hydrate of lime is to be recommended since it is the best form for dusting and the least objectionable on vegetables. For slug control, lime-dusting should be carried out at night or during damp weather. Hydrate of lime is also used for dusting crucifer seedlings to ward off attacks of the turnip flea-beetles, or 'fly'. For this purpose dusting should be undertaken in early morning or evening when the leaves are wet, in order that the dust will adhere.

CHAPTER IX

THE VALUATION AND PURCHASE OF FERTILIZERS

THE farmer cannot secure the best returns from his expenditure upon fertilizers unless he be as efficient in purchasing as in using them, and shrewdness in buying can only come from the knowledge of how fertilizers are to be valued. Many factors must be taken into account in assessing and comparing the values of different fertilizers, but the basis of any calculation must be the unit values of the plant foods. Of the various substances in artificial manures obviously only the four plant foods, nitrogen, phosphoric acid, potash, and lime, are of practical worth to the farmer, and fertilizers are consequently valued on the amounts they contain of the four plant foods. Lime for the time being may be disregarded, since in valuing fertilizers from the standpoint of their effect upon the lime content of the soil, other substances have to be considered in addition to the above four plant foods.

The sale of fertilizers in this country is regulated in many respects by the Fertilizers and Feeding Stuffs Act of 1926. These regulations stipulate that the seller of any fertilizer scheduled in the Act must supply the purchaser with a written statement of particulars of the amounts of nitrogen, phosphoric acid (both soluble and insoluble), and of potash in the fertilizer sold.

The amounts of plant foods present in any fertilizer are stated as percentages, and for fertilizer valuation purposes each 1 per cent. is called a unit; thus a sample of sulphate of ammonia may contain 21 per cent. of nitrogen, or 21 units of nitrogen. The cost of the plant food per unit is obtained by dividing the cost of the fertilizer by the number of units (or the percentage) of plant food it contains. If, for example, the cost of sulphate of ammonia containing 21 per cent. (or 21 units) of nitrogen is £6 per ton, the cost per unit of nitrogen in this fertilizer is £6 divided by 21, i.e. 5*s.* 8½*d.* per unit of N. By the same method, if Nitro-Chalk containing 15½ per cent of nitrogen costs £6 per ton, the cost per unit of nitrogen in Nitro-Chalk is 7*s.* 8¼*d.*

Comparisons of the cost per unit of phosphoric acid are made in a similar manner. Thus, in a sample of superphosphate

containing 14 per cent. of phosphoric acid and costing £3 per ton, the cost per unit of phosphoric acid is £3 divided by 14, i.e. 4*s*. 3½*d*. per unit. In a basic slag containing 12 per cent. of phosphoric acid and sold at £2 10*s*. per ton, the cost per unit of P_2O_5 is 4*s*. 2*d*.

Exactly the same procedure is adopted in obtaining the cost per unit of potash in the various potassic fertilizers; the price per ton is divided by the percentage of potash.

For the calculation of unit prices it is generally most convenient to work on the price per ton basis, but comparisons can of course be made at any other standard weight, e.g. price per cwt. Unless otherwise stated, unit values in Great Britain are always based upon the price per ton of 2,240 lb.

Reliable comparison of unit values cannot be made on the fertilizer prices published in the agricultural press, since quotations for various fertilizers are not all on the same basis. Thus nitrogenous fertilizers are generally quoted delivered buyer's railway station in 6-ton lots, with extras for smaller quantities. Potassic and phosphatic fertilizers are usually quoted f.o.r., i.e. the farmer has to pay for railway carriage, and quotations may be for minimum 6-, 4-, or 2-ton lots, with various extras. Before any correct comparisons of unit values can be made, quotations must be adjusted to delivered costs on to the field, i.e. including rail, cartage, storage, and distribution charges. While all these items cannot always be accurately known at the time a purchase must be decided, they should invariably be estimated and taken into consideration.

In order to illustrate the importance of this point two simple fertilizers may be compared. If, for example, muriate of potash and 30 per cent. salts are quoted f.o.r. at £9 and £5 per ton respectively, their unit prices will be quoted in the agricultural press as 3*s*. 7*d*. for muriate and 3*s*. 4*d*. for the salts, indicating that the latter is much the cheaper source of potash. The farmer, however, is not interested in the cost f.o.r. (free on rail) but only in the cost applied to the crop, that is, the cost of the fertilizer where he can make use of it. He must therefore include railway carriage, carting from station to farm, handling and storage on the farm, mixing charges where the fertilizers are made into a mixed manure, hauling to the field, and distribution. All these charges are to be reckoned at so much per ton

and a common inclusive figure would be about 20*s*. per ton, made up as follows:

	s.	*d*.	
Railway carriage, say . . .	7	6	per ton.
Carting—station to shed . . .	2	6	,,
Handling and storage . . .	1	6	,,
Mixing and screening . . .	4	0	,,
Hauling and distribution . . .	5	0	,,
	20	6	per ton.

Thus, to the above quotations £1 per ton should be added to ascertain the actual real cost of the two sources of potash. The unit values calculated as the cost on to the field become 4*s*. per unit for muriate and 4*s*. per unit in salts. In this particular case, which has of course been taken merely for purposes of illustration, there is no difference in the cost of potash in the two fertilizers, and the final choice would then be determined by less important considerations, such as the better keeping qualities of a mixture made up with muriate instead of salts, or a preference for the latter on light land for sugar-beet.

The above example will serve to emphasize that all transport and handling charges up to and including the final application must be included in the cost figures before the farmer can make comparisons on a unit-cost basis which are of any value; a valuation on any other basis is more likely to mislead than to safeguard him.

Any farmer can easily calculate an approximate standard charge per ton for freight and haulage, storage, mixing, and distribution in his particular circumstances, and should add such of these items as are necessary to the merchant's quotations. Naturally where the price quoted is delivered station or farm he would reduce the extra charge accordingly.

The comparison of unit cost of plant food in simple fertilizers containing only one plant food is obviously straightforward, but it is equally apparent that fertilizers containing two or three plant foods cannot be compared until some unit value has been placed upon each of the food ingredients. One cannot contrast in value two fertilizers having the following analyses:

	Nitrogen.	*Sol*. P_2O_5.	*Insol*. P_2O_5.	K_2O.
A.	4·5%	5·3%	2·2%	6%
B.	8·0%	16·0%	5·5%	12%

until unit costs for nitrogen, sol. P_2O_5, insol. P_2O_5, and K_2O are available. How are they to be decided?

The unit values of the cheapest sources of comparable forms of nitrogen, phosphoric acid, and potash in simple fertilizers are first calculated and used in valuing the units in a compound fertilizer. These unit values must be based on the 'on field' costs of the simple fertilizers. No mixing charge should be included, however, when quotations for two compounds are to be compared. Thus, assuming in a given case that the 'on field' cost per unit of nitrogen, phosphoric acid, and potash are cheapest in the following straight fertilizers:

	£	s.	d.	
Sulphate of ammonia, 20·6 % nitrogen, 'on field' cost .	6	5	0	per ton
Superphosphate, 16 % sol. P_2O_5, 'on field' cost . .	3	9	0	,,
Ground rock phosphate, 27 % insol. P_2O_5, 'on field' cost .	3	0	0	,,
Potash salts, 30 % K_2O, 'on field' cost	6	5	0	,,

the unit prices are respectively, nitrogen 6*s.* 1*d.*, sol. P_2O_5 4*s.* 4*d.*, insol. P_2O_5 2*s.* 3*d.*, K_2O 4*s.* 2*d.* These 'on field' unit values are now multiplied by the percentages, or number of units, of the respective plant foods in the compound or mixed fertilizers, thus:

Fertilizer A.

	£	s.	d.
4·5 % nitrogen @ 6*s.* 1*d.* per unit	1	7	4½
5·3 % sol. P_2O_5 @ 4*s.* 4*d.* per unit	1	3	0
2·2 % insol. P_2O_5 @ 2*s.* 3*d.* per unit . . .		4	11
6·0 % K_2O @ 4*s.* 2*d.* per unit	1	5	0
18 units. Total value of plant foods . .	£4	0	3½

Fertilizer B.

	£	s.	d.
8·0 % nitrogen @ 6*s.* 1*d.* per unit	2	8	8
16·0 % sol. P_2O_5 @ 4*s.* 4*d.* per unit	3	9	4
5·5 % insol. P_2O_5 @ 2*s.* 3*d.* per unit . . .		12	5
12·0 % K_2O @ 4*s.* 2*d.* per unit	2	10	0
41·5 units. Total value of plant foods . .	£9	0	5

It will be noted that no charge was included for 'mixing' in the 'on field' costs of the simple fertilizers from which the unit values were calculated. The farmer can estimate his own mixing costs per ton with sufficient accuracy, and when he wishes can compare them with the charge for this work made by the seller of a compound fertilizer.

Thus, supposing the 'on field' cost of compound 'A' above to be £6 per ton, the charge made for mixing is obviously £1 19*s.* 8½*d.* per ton. Since the mixture contains 18 units of plant foods, the mixing charge is $\frac{£1\ 19s.\ 8d.}{18} = 2s.\ 2\frac{1}{2}d.$ per unit. If the 'on field' cost of mixture 'B' is £11 per ton, the charge for mixing is £11 less £9 0*s.* 5*d.* = £1 19*s.* 7*d.* per ton, or 11*d.* per unit, hence fertilizer 'B' is considerably cheaper than fertilizer 'A', although the charge per ton for mixing happens to be the same in both fertilizers. This will be readily appreciated when it is remembered that fertilizer 'A' involves the mixing, bagging, transport, and handling of much more inert matter than fertilizer 'B'. In comparing two compound fertilizers it is therefore misleading to assess the mixing charges at so much per ton; mixing charges should be assessed on a unit basis. The only reliable means of comparing the values of compound fertilizers is by applying 'on field' unit values to all the plant foods and subsequently comparing the mixing charge per unit. It should not be forgotten that the charge for mixing includes the manufacturers' knowledge and experience in making satisfactory blendings, as well as the cost of the actual mixing operation.

It has been pointed out previously that the unit values of nitrogen, phosphoric acid, and potash are not the only plant foods to be considered in assessing the value of a fertilizer, and that lime is also an important factor. Some fertilizers increase the rate at which lime is lost from the soil, whereas others tend to diminish the natural loss of soil calcium. Are these effects in practice worthy of inclusion in assessing the cost of a fertilizer, and if so, what values are to be placed upon them? The latter must obviously depend first upon the cost of lime, and secondly upon the desirability of increasing or decreasing the lime in the particular soil under consideration.

Lime may be bought in various forms of quicklime (CaO), hydrated lime ($Ca(OH)_2$), and carbonate of lime ($CaCO_3$). In accordance with the Fertilizers and Feeding Stuffs Act the seller of any form of lime must state the percentage of lime in terms of calcium oxide (CaO), so that it is a simple matter to value various forms of lime on the basis of the cost per unit of CaO. It need scarcely be emphasized that the comparative costs must

include transport and application as already explained for the valuation of fertilizers. Thus, if a farmer wished to apply the equivalent of 20 tons of quicklime to a field and were offered the following materials:

	£	s.	d.	
Lump lime (90 % CaO) loose in truck, delivered railway station	2	5	0	per ton
Ground lime (85 % CaO) in 1-cwt. bags, delivered railway station	2	10	6	,,
Hydrated lime (72 % CaO) in 1-cwt. bags, delivered railway station	3	0	0	,,
Ground limestone or chalk (50 % CaO) in bags, delivered on farm	1	7	6	,,
Lump chalk (40 % CaO), delivered on farm . .		15	0	,,

he would estimate their respective values on the following lines:

Lump Lime. Station cost £2 5*s.* per ton; haulage station to field 5*s.*; carting out in heaps 1*s.* 3*d.*; spreading heaps after slaking 9*d.* Total £2 12*s.* per ton.

Cost per unit of CaO = 7*d.*

Ground Lime. Station cost £2 10*s.* 6*d.* per ton; haulage to field 4*s.*; application by manure distributor 2*s.* Total cost £2 16*s.* 6*d.* per ton.

Cost per unit of CaO = 8*d.*

Hydrated Lime. Station cost £3 per ton; haulage to field 4*s.*; application 2*s.* Total cost £3 6*s.* per ton.

Cost per unit of CaO = 11*d.*

Ground Limestone. On farm cost £1 7*s.* 6*d.*; application 2*s.* 9*d.* Total cost £1 10*s.* 3*d.* per ton.

Cost per unit of CaO = 7*d.*

Lump Chalk. On farm cost 15*s.* per ton; application 1*s.* 6*d.*; extra harrowing 2*s.* Total cost 18*s.* 6*d.* per ton.

Cost per unit of CaO = 5½*d.*

The above costs are, of course, hypothetical and the farmer would naturally make his own estimates in accordance with his particular circumstances. As explained earlier, not all forms of lime are equally suitable for all conditions, and in some cases certain forms would be automatically ruled out for consideration. Assuming, however, that any of the above are suitable, then lump chalk at these prices is the farmer's cheapest source of CaO.

When the farmer is in a position to determine the cost of lime he may take into consideration the value of the effects of various

fertilizers on the lime content of the soil. For this purpose the saving or loss of the calcium carbonate in the soil which may be anticipated from the use of 1 ton of various fertilizers has been dealt with in Chapter VI.

Compound fertilizers containing nitrogen as ammonia will increase the loss of lime in the proportion of their ammonia content to that in sulphate of ammonia.

For the manuring of a soil seriously deficient in lime the amount of lime supplied or lost through use of fertilizers should be taken into account in arriving at the unit cost of fertilizers. Thus, if the 'on field' cost of sulphate of ammonia be £6 5*s.* per ton and that of nitrate of soda £7 per ton, before comparing their values on an acid soil where either can be suitably used, allowances should be made for their effect on the soil lime. Using the above cost of ground limestone, about £1 11*s.* 6*d.* must be added to the cost per ton of sulphate of ammonia, and 8*s.* deducted from that of nitrate of soda. The costs of the fertilizers then become £7 16*s.* 6*d.* per ton for sulphate of ammonia and £6 12*s.* per ton for nitrate of soda, and the unit prices of nitrogen 7*s.* 7*d.* and 8*s.* 3*d.* respectively.

On a clay or heavy silt soil the 'lime value' of nitrate of soda may be more than offset by its tendency to destroy tilth and induce the soil to cap. Moreover, the difficulties in handling and application of nitrate of lime and calcium cyanamide may in the opinion of the farmer outweigh the value to be placed upon their lime-saving capacities. Rarely can the 'lime value' of basic slag be weighed against the more rapid action of superphosphate, or the saving of lime through the use of nitrate of soda be valued against the better retention by the soil of nitrogen applied in the ammonium form. These and many other points merely serve to emphasize that the farmer is never in a position to compare the values of different fertilizers with mathematical precision. He is justified in comparing 'on field' cost unit values in fertilizers supplying the plant foods in suitable form for his purpose, and on soils where the lime problem is acute he may well take the 'lime value' of fertilizers into some consideration. Of the many other factors, such as condition of fertilizer for distribution, storage, handling, rapidity of action, &c., he will often make his decision without attempting to put a money value on these items.

Residual Values.

The Agricultural Holdings Act, 1923, stipulates that a tenant farmer on quitting his holding shall receive compensation from the landlord for the value of the unexhausted residues of fertilizers applied during the tenancy. Compensation is to be assessed on the basis of the fair value of the fertilizer residues to an incoming tenant, and consequently the prices paid for fertilizers by the out-going tenant should not be taken into consideration in making the in-going valuation. The incoming tenant is merely taking over so many pounds of nitrogen, phosphoric acid, potash, and lime, and should obviously pay for these only what their cost would be if he had to apply such quantities at the time of entering upon his tenancy. Hence the current unit cost of plant foods on to the field should be the basis of assessment, and the prices paid by the out-going tenant are quite irrelevant.

The residual effect of a fertilizer varies widely and is governed by the kind of soil, the cultivations, the climate, the crops grown, and the nature and amounts of other fertilizers applied in conjunction with any particular one under consideration. For example, the residual value of the potash in a heavy dressing of kainit on a clay or silt soil may be more than counter-balanced by the destruction of the tilth, or an excessive dressing of an organic nitrogen manure to fruit may do harm to many times the value of the fertilizer residues. Under some conditions there may be no available phosphates after the year of application of phosphatic manures. There are many such points to be taken into consideration in estimating the residual values of fertilizers and it must be frankly admitted that dependable information is all too meagre to supply the foundation necessary for a fair valuation in all cases. Moreover, even the knowledge at present available cannot always be employed, since the majority of farmers do not record the necessary particulars of their farming operations. For these and other reasons the tenant-right valuation of fertilizer residues is almost invariably made in a very crude and arbitrary fashion. Since the Act gives no indication of the methods to be followed in the determination of the unexhausted values of fertilizers, scales of compensation have been composed by the various local associations of agricultural

Basis of Compensation for Residual Values of Fertilizers.

Fertilizer.	*Proportion of the original Plant Food assumed to remain in the Soil and to rank for Compensation.*						
	Arable Land.			*Grassland.*			
	after 1st crop.	*after 2nd crop.*	*after 3rd crop.*	*after 1st year.*	*after 2nd year.*	*after 3rd year.*	*after 4th year.*
Sulphate of ammonia. Nitrate of ammonia (Nitro-Chalk). Nitrate of lime. Nitrate of soda. Calcium cyanamide. Urea. Dried blood.		Nothing			Nothing		
Peruvian guano.	$\frac{1}{3}$	$\frac{1}{6}$	..	$\frac{1}{3}$	$\frac{1}{6}$	..	..
Hoof and horn meal. Shoddy and wool waste. Fur waste, hair.	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	..
Fish guano. Meat meal.	$\frac{1}{3}$	$\frac{1}{6}$	..	$\frac{1}{3}$	$\frac{1}{6}$	..	..
Manure cakes.	$\frac{1}{5}$	$\frac{1}{10}$	..	$\frac{1}{5}$	$\frac{1}{10}$	..	..
Superphosphate.	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{6}$	..
Dissolved bones.	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{12}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{12}$	..
Bone meal. Steamed bone flour.	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{6}$
Basic slag. Ground rock phosphate.	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$
Kainit and potash salts, muriate, and sulphate of potash.	$\frac{1}{2}$	$\frac{1}{4}$	..	$\frac{1}{2}$	$\frac{1}{4}$	..	..
Compound manures.	$\frac{1}{3}$	$\frac{1}{6}$	..	$\frac{1}{3}$	$\frac{1}{6}$	..	..
Lime—oxide.	Deduct 4 cwt. per acre	Deduct 8 cwt. per acre	Deduct 12 cwt. per acre	Deduct 4 cwt. per acre per year.			
Lime—carbonate.	Deduct 7 cwt. per acre per year.			Deduct 7 cwt. per acre per year.			
Dung.	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	..

valuers for the guidance of their members. Such scales are based almost entirely upon the data from a very limited number of investigations conducted under a particular system of farming and climate. They should only be regarded as a very general guide, subject to considerable modification and adjustment in their application to varied circumstances, and they should in no case be accepted as an immutable doctrine.

The table on page 115 indicates the type of scale in common use, but scales vary in many particulars from district to district.

CHAPTER X

ECONOMICS OF THE USE OF FERTILIZERS

The object of the use of fertilizers is not necessarily to secure a big crop, but to ensure the supply of the plant foods required to obtain the most profitable crop under any particular set of circumstances. Obviously, fertilizers are only one factor in determining both the yield of a crop and its cost of production, and while in most cases the reason for applying fertilizers is to increase the yield otherwise obtainable without manuring, the increased yield must be secured at such a cost that the final margin between total production costs and receipts is widened or narrowed according to whether the crop is grown at a profit or loss. The judicious use of fertilizers will increase profits or diminish losses, but fertilizers wrongly applied may readily have the reverse effects.

Unfortunately it is quite impossible to determine accurately the optimum amounts of plant foods desirable for any particular set of conditions, and this will hold true until the effects of weather upon the soil, crop development, and harvesting, the influence of insect and fungus attacks, and the course of agricultural prices can be accurately forecast before the crop is sown. Weather alone is frequently responsible for crop-yield variations of more than 50 per cent., while modern transport developments have completely eliminated any correspondence between local yields and prices. Fertilizers can, however, contribute towards the mitigation of adverse weather conditions.

The amounts of plant foods removed by a particular crop cannot be used as the sole criterion of the plant nutrients to be returned to the soil for the succeeding crop, although such a guide would be useful in the absence of better information during long periods of stable prices. The majority of soils contain enormous stores of phosphoric acid, potash, nitrogen, and calcium, but apparently only a small proportion of these plant nutrients in the soil can be made available during a single season for the growth of a crop. Seldom do the available amounts of the soil nutrients provide for the crop yield which is most profitable, and the fertilizer applied should be designed to

supplement the available soil nutrients to the extent necessary to give the most profitable crop under average conditions. These requirements may not bear any relation to the amounts and proportions of plant nutrients removed by the various crops, and since the wide variations in yields arising from other factors have been emphasized, it will be appreciated that the nutrients to be supplied must be based upon what have proved best on the average results over a series of different seasons and soils. It may be contended that separate averages of crop yields on the different classes of soils should be taken as the basis for formulating manurial dressings for different soil types. Although there is some justification for so doing, it must be remembered that a single field, wholly under the one crop, often shows considerable soil variation and it would be impracticable to attempt to vary the fertilizer treatment accordingly. Moreover, it is without any question more economic to rely upon a minimum number of fertilizer mixtures for the whole farm, which will give the advantages of bulk buying, than to use a relatively numerous range of different compounds entailing as many separate mixings, none of which can be known with certainty beforehand to be the best mixture for the particular season to follow.

Before deciding the amounts and proportions of the plant foods to be supplied in fertilizers to any crop, some broad indication is desirable of the increased yields likely to be obtained under average conditions from standard quantities of nitrogen, phosphoric acid, and potash. Given such information it should not be difficult to decide upon rates of application in relation to other production costs and anticipated crop prices. Such knowledge can only be provided by fertilizer experiments designed to give reliable data, and the large amount of investigation which has been undertaken over many years has provided very useful information in this regard for many of the widely cultivated farm crops. For the manuring of other crops, however, reliable information is all too scanty, and at present it is necessary to rely to a considerable extent upon the practices of successful cultivators. In the past, farmers were frequently recommended to lay down single experimental plots to test the effect of a particular fertilizer treatment, but for the most part no dependable information as to the extent of the yield difference resulting from the treatment can be given by such simple

trial plots. Only where the results from a number of similarly treated plots are available can any reliable quantitative data be obtained.

Moreover, even where the increases obtained from fertilizer treatments are established by reliable experiment, it still remains for the farmer to interpret them in terms of farm practice. This would not appear to be difficult, but judging from the claims of some fertilizer vendors and from the publications of more altruistic sources, it would seem that some explanation of the interpretation of fertilizer trials is often required. It is not by any means uncommon to see advertisements and statements like the following:

	Yield.	*Value.*	*Cost of Manure.*	*Extra profit from X.Y.Z. Manure.*
No fertilizer . .	8 tons p.ac.	£17	..	..
5 cwt. X.Y.Z. manure .	10 ,, ,,	£21 5*s*.	£2	£2 5*s*.

It is quite possible that the use of 5 cwt. X.Y.Z. manure did result in an extra profit of £2 5*s*. per acre on this particular crop, but there is nothing in the above statement which would justify one in concluding that such an extra profit had been obtained, or in fact that any additional profit was secured from the use of the fertilizer. In the first place the true cost of the fertilizer is rarely given in such statements; the cost figure quoted is almost invariably a proportionate figure calculated on minimum list prices and makes no allowance for haulage, handling, storage, distribution, extras for small quantities, or credit, for some or all of which the farmer has to pay. Moreover, the crop is seldom valued, but the average market price is simply multiplied by the yield per acre to provide the figure given as the total value of the crop. The value per unit weight may, however, be increased or decreased as a direct result of using fertilizers. On potatoes, for example, fertilizers affect the quality, the incidence of disease, the proportion of saleable ware, and time of maturation, all of which directly bear upon the market value of the crop. Similarly the quality of grain may be improved by securing a bolder sample through the use of fertilizers, or the grain may be inferior as the result of lodging or late ripening encouraged by fertilizers wrongly used. A

pasture, hay, or forage crop can be greatly increased in value per ton by the use of fertilizers either for influencing the proportion of leguminous plants in the crop or for inducing an earlier, richer, and more succulent development of other species. On the other hand, fertilizers wrongly used may greatly diminish the value of the crop per ton. On many market-garden crops the yield per acre may be considerably increased by certain fertilizer dressings, but if they result in delayed maturity the best market prices may easily be missed and possible profit turned into a loss. Many other examples could be given, but the foregoing are sufficient to explain that bald figures of crop values in fertilizer experiments are not in themselves sufficient.

A third criticism of the statement of results of fertilizer trials is of even greater moment than those outlined above, and is concerned with production costs apart from the cost of fertilizers. Under nearly all circumstances an increase in crop is accompanied by increased costs per acre of harvesting and marketing, though usually by decreased costs for these items per unit weight of crop. Obviously a 12-ton crop of potatoes costs more per acre to harvest than a 6-ton crop, and a 7-quarter crop of wheat costs more per acre than a 4-quarter crop to cut, carry, thresh, dress, bag, and haul to market. Fertilizers beyond the cost of their application do not appreciably affect the cost per acre of growing a crop up to the stage of harvesting, but if increased yields are obtained the costs per acre of harvesting, haulage, storage, and any other subsequent treatment must be increased. In most circumstances these extra harvesting and subsequent costs will be proportionately less per ton than where a smaller crop is obtained without using fertilizers, but in some cases the larger crop may even cost more per ton for harvesting, &c., than the smaller crop. The latter statement is not infrequently true for hay and cereal crops in districts subject to frequent rains during summer, where a heavy hay crop cannot be quickly cured and is consequently spoilt, and heavy cereal crops are subject to lodging.

In assessing the return from the increased yield due to fertilizers, not only must the cost per acre for fertilizer treatment be deducted from the market value of the increased yield, but deductions must also be made for a proportion of the costs per acre for harvesting, hauling, storage, threshing, dressing, bag-

ging, &c. Thus, in the example given previously, supposing this to relate to sugar-beet, the cost of harvesting and hauling to the factory might be £5 per acre on the 8-ton crop, or 12*s*. 6*d*. per ton. It would be reasonable to assume that the extra 2 tons per acre obtained by using fertilizers also cost 12*s*. 6*d*. per ton for harvesting and haulage, and consequently the extra profit from the use of manure is really £1 per acre, plus the value of any extra 'tops' and the residual value of the fertilizer, minus the cost of applying the fertilizer.

Before applying fertilizers the farmer should satisfy himself he will be in a position to deal satisfactorily with the increased crop and to obtain the full benefit from it. Reference has already been made to possible difficulties with heavy hay crops and the manuring of pasture may also be open to objections in certain circumstances. It would be foolish to expend money on fertilizers for the improvement of pastures if sufficient live stock were not available to utilize the extra grazing provided, or if it would be inconvenient to conserve the extra herbage. On the other hand, it might well pay a farmer to manure his pasture heavily even at the expense of other crops, since if he be producing milk he may obtain the full return on nitrogenous fertilizers on pasture within a few weeks, i.e. his capital is locked up for a very short period as compared with that invested in arable crops. It need scarcely be emphasized that where the supply of capital is restricted for the manuring and cultivation of crops, the general principle should be to expend the available money first in those directions likely to yield the biggest and quickest return. Only when the most profitable means of outlay have been fully exploited should capital investment be increased in the production of less profitable crops. This naturally leads one to consider the merits of the still common practice of manuring for a rotation of crops in place of manuring each crop individually. Except during long periods of stable prices for agricultural products, fairly constant production costs and the absence of severe fluctuations in other factors affecting farm organization, there can be little justification for the stereotyped pre-determined sequence of crops commonly termed a 'rotation'. In the past, various rotations were evolved in different parts of the country during the long periods when agricultural conditions changed very little or very slowly, and in those circumstances

the settled rotation of crops was a practice offering many advantages in the general organization of the farm. Ever since 1914 the conditions necessary for the most successful prosecution of the rotational system of farming have not obtained. The successful farmer has been compelled to adapt his cropping each and every year to meet the exigencies of the immediate future, and largely irrespective of what has gone before and what it may be necessary to grow two or three years ahead. With the development of agricultural machinery and fertilizers, the farmer to-day has far greater freedom in his choice of crop than his predecessors of last century, and to a farmer with reasonable capacity for organization the settled rotation of crops should be a matter of little but historical interest.

During periods of stable prices the rotation did offer obvious possibilities for simplified manuring; for example, practically the whole of the animal manure, phosphatic and potassic fertilizers applied during a four- or five-year course could be given to the root crop. The root crop was also generally regarded, though sometimes quite wrongly, as a cleaning crop, and a later crop of clover was depended upon to supply a big proportion of the nitrogen required by the cereals in each rotation. The system demanded profitable prices for both live stock and cereals; no single crop could be greatly increased or decreased in area in any one year without seriously upsetting the whole farm routine. In fact, some crops were often grown at a loss in order that the routine could be maintained. It is to be hoped that such dependence on rule of thumb has gone for ever and that farmers will become equipped to adjust their cropping to the probabilities of profits; that instead of sinking capital in the land on which they do not expect the full return for a period of several years, each crop will be cultivated and manured individually to secure the biggest and quickest return on expenditure. While the farmer should naturally take into account the previous treatment of the land, there should be no question of forecasting the future and manuring for a prescribed rotation; as a general principle manuring of arable land should be decided for each crop and of grassland for each season.

Earlier reference has been made to the principle of 'balanced manuring', and evidence continues to accumulate which shows that over a wide range of soils and climatic conditions in this

country, there are for certain crops fairly well-established proportions of plant nutrients which have generally given profitable crop increases. It need not be further stressed that the best proportions and quantities of fertilizer nutrients in one season will not necessarily be the best for the same crop during another season, on account of the effects of the influence of weather upon a number of factors in crop production. Such factors frequently outweigh the variations in response to fertilizers of different soil types, and since weather effects cannot be foretold, the balance of the plant nutrients to be applied must be decided upon in the expectation of an approximately normal season. It is not suggested that any one crop should receive identical manuring no matter under what conditions it is grown, but it is desired to emphasize that soil conditions must differ very markedly to justify alterations in fertilizer recommendations. In the succeeding section 'balanced' or complete fertilizer dressings for the various crops will be recommended, with an indication of the modifications justified by differences in soil types, &c.

If a farmer be satisfied that his present fertilizer dressings give him on the average the best yields he can reasonably expect under his present circumstances, it does not follow that the proportions of the plant nutrients should never be modified. His object is not to grow the biggest crops but the most profitable, and should the relative prices of plant nutrients greatly alter, it may be desirable to modify his manurial formulae accordingly, particularly if crop prices are low and if fertilizers are an important item in the total costs of production. This point is seldom likely to be of much moment to growers of high-priced crops, e.g. fruit, glasshouse, and market-garden crops, but on the other hand it will much more readily come into play in grassland and mechanized cereal farming.

For practically all crops there is much to be said in favour of fertilizer dressings supplying the three plant foods, nitrogen, phosphoric acid, and potash. Although the 'complete' dressing will not be the most profitable in every season, it provides greater assurance that the manurial requirements of the crop will be satisfied, and that the plant will be better able to adjust itself to variations from the normal season.

In addition to the proportions in which the plant nutrients are applied, the farmer must decide upon the most economical

sources of nitrogen, phosphoric acid, and potash from which to make up his fertilizer dressings. This aspect of the economics of manuring has been dealt with in the earlier chapter dealing with the purchase and valuation of fertilizers.

There is great divergency of opinion on the relative merits of inorganic and organic fertilizer materials as sources of nitrogen and—to a smaller extent—of phosphoric acid. While there is considerable scope for investigation on this subject, there is a certain amount of reliable information available which quite definitely shows that on ordinary farm crops nitrogen and phosphoric acid from organic sources are rarely as efficient as the inorganic forms. The matter is one on which generalization is difficult owing to the great variation in the organic materials, but for ordinary farm crops under British conditions the organic fertilizer materials do not justify so high a unit price as the inorganics. It should, however, be made clear that the statement refers to the plant nutrients contained in organic manures, since vegetable matter also serves to maintain or increase the humus in the soil and has valuable effects on soil texture. It need scarcely be pointed out, however, that vegetable matter will have an appreciable influence upon soil humus only when applied in large quantities, i.e. bulky applications of farmyard manure, the ploughing-in of stubbles or temporary leys. The effect of the amount of organic matter applied in a few bags of an organic fertilizer will be quite insignificant in directly increasing the amount of soil humus. There are numerous instances on all classes of soil, and including the cultivation of all the common farm crops, where the soil fertility has not only been maintained but increased without the use of any organic fertilizer excepting the ploughing-in of crop residues. Reference has been made to the fallacy of converting crops into animal manure at a direct loss. Organic manures are slower in action than the inorganics and some contain nitrogen which may become available slowly over more than one season. This characteristic may be a valuable feature in certain branches of production, so far as our present knowledge enables us to judge, but on the other hand is a decided disadvantage in other types of cultivation; there are, for example, many cereal crops which suffer from large quantities of organic residues especially in districts of heavy rainfall.

Despite the great value of fertilizers in crop production, they are not to be regarded as a remedy for defects in the other elements of good husbandry. A fertilizer dressing entirely justifiable on one farm may not be the best for the same crop, on the same soil, and in the same climate but on another farm which is differently organized; the same type of fertilizer would be required in the two cases, but the most profitable rates of application may vary appreciably. The scale of using fertilizers must be decided upon in relation to the general efficiency of farm management, organization and equipment, marketing arrangements, position in regard to buying and the financing of crop production, and the scale of operations. The better and more efficient these items, the higher will be the rate at which fertilizers can be profitably employed. Fertilizers can never make up for lack of good cultivations, efficient drainage, good seed, neglect or inability to take full advantage of favourable weather conditions, or failure to control crop pests—weeds, insects, and diseases—though fertilizers may considerably mitigate the effects of these unfavourable factors. In nearly all cases, however, the most satisfactory course is the direct removal or rectification of such unfavourable influences before a heavy outlay is made upon fertilizers. Finally, it must be remembered that manuring is only one item in the total costs of crop production, and that as the other costs alter so it may be desirable to vary the outlay upon fertilizers, even though fertilizer and crop prices do not undergo any material change; for example, an increased use of mechanical power should, by cheapening work, enable the farmer to profitably invest larger amounts in fertilizers if crop prices are steady. Further, if crop prices fall, and fertilizer prices fall to an even greater degree, it does not necessarily follow that more fertilizers may be used or even that former rates should be maintained. On the other hand, a rise in crop prices does not in itself justify any increased outlay upon fertilizer; but it does indicate that a review of all crop expenditure and receipts is required in order that the various items may be adjusted to the best advantage in the new circumstances. Manuring is one indispensable item in crop production, but consideration of it except in relation to the other factors is of little utility.

CHAPTER XI

GUIDE TO THE MANURING OF FARM CROPS

THE previous chapters have been devoted to a brief description of the objects of manuring, the different circumstances under which fertilizers have to be used, and the effects of other factors upon fertilizer requirements.

Account has been given of the four plant nutrients, nitrogen, phosphoric acid, potash, and calcium, and of the fertilizer materials available to farmers. The principles on which such materials should be purchased and used have been considered in some detail, and finally some guide is required of the amounts of the plant nutrients which should be applied to various crops. Much of the previous pages has described the many influences and factors which, as they vary in relation to one another, affect the amounts and proportions of the plant nutrients considered necessary for the most profitable yields, and when all the factors are considered separately they would seem to entail endless modifications and adjustments in fertilizer dressings. When, however, a comprehensive review of all circumstances is made, and particularly when due consideration is given to the influence of such major items as weather and prices, it has been emphasized that there can be no justification for trivial differences in fertilizer recommendations. This principle underlies the ensuing notes on the manuring of the important British farm crops, and while they cannot claim to cover all conceivable circumstances, information has been given in the earlier chapters to indicate the direction in which modifications should be undertaken. Where unusual special circumstances exist, the best course for the ordinary farmer will be to obtain expert opinion before making his final decision.

The recommended dressings are given in pounds of nitrogen, phosphoric acid, and potash per acre, and the 'balance' or proportions of the plant nutrients in many of the mixtures is also shown. The amounts of fertilizers required to supply the suggested quantities of plant foods may easily be calculated from the following table:

Pounds of Plant Foods in 1 cwt. of Fertilizer (usual analysis).

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	N.	P_2O_5.	K_2O.
Sulphate of ammonia	23	..	..
Ammonium chloride	28	..	..
Ammonium phosphate (mon.)	13¾	63	..
,, ,, (di.)	23	60	..
Ammonium nitrate	39	..	..
Nitro-Chalk	17½	..	..
Nitrate of soda	17½	..	..
Nitrate of lime 13 % N	14½	..	..
,, ,, 15½ % N	17½	..	..
Nitrate of potash 12 % N and 40 % K_2O	13½	..	45
Calcium cyanamide	23	..	..
Urea	51½	..	..
Hoof and horn 13 % N	14½	2¾	..
Dried blood 12 % N	13½	1	½
Meat meal 6 % N	6¾	12½	1
Fish guano 8 % N	9	10	..
Shoddy 10 % N	11	..	..
Waste cakes 5 % N	5½	2¼	1
Soot 4 % N	4½	..	..
Superphosphate 14 % P_2O_5	..	15½	..
,, 16 % P_2O_5	..	18	..
Basic slag 18 % P_2O_5	..	20	..
,, ,, 12 % P_2O_5	..	13½	..
Ground rock phosphate 27 % P_2O_5	..	30	..
Bone meal 4 % N+22 % P_2O_5	4½	24½	..
Steamed bone flour 27 % P_2O_5	1½	30	..
Dissolved bones 16 % P_2O_5	2¾	18	..
Bone charcoal	..	38	..
Kainit	..	..	16
Potash salts 30 %	..	..	33½
,, ,, 20 %	..	..	22½
Muriate of potash	..	..	56
Sulphate of potash	..	..	55
Sulphate of potash—magnesia	..	..	28
Kelp 18 % K_2O	..	..	20
Dried poultry manure	4¾	3¼	1½
Guano 6 % N+22 % P_2O_5	6¾	24½	..
,, 12 % N+15 % P_2O_5+3 % K_2O	13½	16¾	3½

The grounds for the selection of the kinds of fertilizers to be used have been described previously, and very brief reference is made in the following recommendations only to particular soil conditions. The crops are considered individually under the following sections: root crops, grain and seed crops, forage crops, grassland, market-garden crops, and outdoor fruit.

ROOT CROPS

Potatoes.

Free-working soils containing plenty of organic matter give the biggest crops, and where organic matter is not provided by the ploughing-in of crop residues, i.e. temporary leys, grass, seaweed, rye, or other green manure crops, some farmyard manure should be given if available. In most districts the dung should be ploughed in during autumn, but in wet localities better results are usually obtained from spring applications. Better yields and quality are secured from moderate dressings of dung along with fertilizers than from heavy dressings of dung alone. Where the soil organic matter is not meagre, satisfactory crops are obtained with fertilizers alone where dung is not available. Where farmyard manure is to be applied, the usual rate should be 10 to 12 tons per acre.

Potatoes generally thrive best on slightly acid soils, and although benefit has resulted from liming extremely acid potato soils, it is seldom advisable to apply lime immediately before the potato crop. Potato scab is most common on alkaline soils or after liming, and 'blight' is also said to be more prevalent on alkaline soils in some districts.

In the following fertilizer dressings the nitrogen should always be ammonia nitrogen, the phosphoric acid should be water-soluble, and the potash derived from either muriate or sulphate. Muriate may be used for 'earlies' and for 'maincrops' except where the sulphate is known to give better quality. 'Quality', of course, is merely a matter of personal taste, where a potato is wanted which is floury after boiling, the sulphate is usually best; where a chipping or frying potato, or one with a firm and waxy flesh is needed, then muriate is likely to be best for this standard of quality. Unless the grower knows the effects of the two types of potash on his particular soil, and knows also by what standard his buyer will judge potatoes, he may prefer equal amounts of muriate and sulphate of potash. As a general rule there is little to choose between the two high-grade potash fertilizers, especially in good rainfall districts, but potash salts and kainit are inferior.

If farmyard manure, or seaweed, &c., is not applied, the rates of application may be increased by one-third. Where a thick clover-ley dressed with farmyard manure is ploughed in, the dressing recommended for organic soils should be followed,

especially in districts of heavy rainfall. All fertilizers should be applied before planting, but on light, open soils in heavy-rainfall districts some of the nitrogen may be reserved for a top-dressing before the final earthing-up; the top-dressing may be applied either as ammonia or nitrate nitrogen, the latter particularly for 'earlies'.

Recommended Rates of Application of Plant Foods.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Maincrop Potatoes:						
Heavy loams	70	70	110	2	2	3
Sandy and light soils	70	35	140	2	1	4
'Organic' soils, fen, moss, &c.	30	90	90	1	3	3
Silts	90	45	140	2	1	3
Early Potatoes	60	60	90	2	2	3

When applied in a complete and correctly proportioned fertilizer dressing, each pound of nitrogen should on the average increase the yield by about 1 cwt. per acre of maincrop potatoes.

The plant nutrients removed in 1 ton of potatoes are 8 lb. of nitrogen, 3 lb. of phosphoric acid, 12 lb. of potash.

Sugar-beet.

Soil organic matter is relatively less important for the cultivation of sugar-beet than for potatoes, but it is valuable in the early stages of the crop as affording some protection against spring droughts. Consequently where farmyard manure is available it can be used advantageously on sugar-beet unless organic matter has been amply provided from the preceding crop. Farmyard manure for sugar-beet should be ploughed in during autumn at the rate of 10 to 12 tons per acre. Spring dressings of dung encourage fangy roots.

Lime deficiency is frequently the cause of unsatisfactory crops, since sugar-beet is very sensitive to acid conditions. A regular plant and satisfactory development cannot be obtained on soils lacking in lime, and partial or complete failures are to be expected on soils testing less than pH 5. On acid soils, a suitable dressing of lime or chalk should be harrowed in after

the final ploughing. Much of the money spent on the cultivation of the beet crop will be thrown away if the lime content of the soil is unsatisfactory, and where this is suspected the farmer's first step should be to have his soil examined.

Both ammonia nitrogen and nitrate nitrogen are suitable for sugar-beet, nitrate nitrogen being preferable on acid soils, especially in districts of very low rainfall. The best results are obtained from applying all the nitrogen in the seed-bed, except possibly on very light, open soils where part of the nitrogen should be reserved for top-dressing. Naturally on other soils, if continuous wet weather delays seeding after fertilizers have been applied, it may be necessary to give a nitrogenous top-dressing if the crop is checked. Late dressings of nitrogen are undesirable since they delay maturity and tend to result in lower sugar percentages. As a rule phosphates have little effect upon sugar-beet apart from encouraging early establishment of the seedlings, and for this purpose the phosphoric acid should always be given in easily soluble form. Generally, the water-soluble forms are most suitable, but on acid soils high-soluble basic slag is also satisfactory. Despite the large amounts of potash removed in the beet crop it does not respond to very heavy dressings of potash manures, particularly on good soils and where farmyard manure has been applied. Beet frequently responds to light dressings of salt, and hence potash salts, or kainit on very light soils, are suitable sources of potash for beet.

It has frequently been demonstrated that soluble fertilizers result in a quicker development of the young plant than do organic and other less readily available fertilizers. Moreover, it is advisable to work the fertilizers deeply into the seed-bed since there is some evidence that surface applications encourage surface rooting and on light soils may injure germination.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Light and sandy soils	60	45	90	4	3	6
Loams . . .	50	50	75	2	2	3
Clay soils . .	50	75	50	2	3	2
Organic soils, fen, &c.	20	60	60	1	3	3

In the presence of adequate amounts of phosphoric acid and potash, each pound of nitrogen will increase the yield by nearly $\frac{1}{2}$ cwt. of roots and 1 cwt. of tops per acre.

A ton of sugar-beet roots removes $6\frac{1}{2}$ lb. of nitrogen, 2 lb. of phosphoric acid, 8 lb. of potash, and a ton of beet tops $10\frac{1}{2}$ lb. of nitrogen, $2\frac{1}{2}$ lb. of phosphoric acid, 15 lb. of potash.

Mangolds.

On many soils organic matter is of considerable value in securing conditions conducive to good germination and quick development of the seedling plants, and, after potatoes, probably no other root crop responds better than mangolds to farmyard manure. Where supplies are available the rate of application should be about 15 tons per acre, ploughed in during autumn. Mangolds are often grown continuously on the same piece of land, and this should be situated near the homestead in view of using heavy dressings of farmyard manure. In such circumstances the application of animal manure may be increased to 20 tons per acre. In districts of heavy winter rainfall the farmyard manure is better ploughed in during early spring, but in this case the manure must be well rotted.

Mangolds are susceptible to any lack of lime in the soil and where soil acidity is marked, satisfactory crops cannot be grown. Where the soil is thought to be short of lime, or where failure of the mangold crop has been experienced, the soil should be examined for lime shortage and any deficiency must be rectified by a suitable dressing of lime or chalk.

As for potatoes and sugar-beet, the chief plant food requirements are nitrogen and potash, phosphoric acid having relatively small influence upon yields. The bulk of the nitrogen should be ammoniacal and harrowed into the seed-bed before sowing, but about a third of the nitrogen should be applied in the nitrate form as a side-dressing after singling. On heavy-textured, acid soils, to which lime has not been applied, the whole of the nitrogen, both seed-bed and side-dressing, can be applied in the nitrate form. In most circumstances phosphoric acid should be supplied in water-soluble form, but on lime deficient soils the phosphates may be given in high-soluble basic slag or bones.

Potash usually gives the best results when applied as salts or kainit, the latter being restricted to light soils. On the other

hand on light soils where potash is not given in the form of kainit an application of about 3 cwt. of common salt per acre may be given.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Light soils	40	40	60	2	2	3
Loams	70	35	70	2	1	2
Clay soils	75	50	50	3	2	2
'Organic' soils	50	30	75	2	1	3

In a properly balanced fertilizer dressing each pound of nitrogen may be expected to increase the yield of roots by about $1\frac{1}{2}$ cwt.

A ton of mangold roots removes from the soil about 5 lb. of nitrogen, 2 lb. of phosphoric acid, and 10 lb. of potash.

Swedes and Turnips.

The amount of soil organic matter is not so important a factor in the cultivation of swedes and turnips as for the root crops previously considered. Satisfactory yields can be secured in most seasons, except on the light soils in dry districts, with fertilizers alone, but if farmyard manure is available it may be applied in moderate dressings of 8 to 10 tons per acre for swedes and turnips. On the lighter classes of soil, moderately good yields can be obtained from dung without the aid of fertilizers. The following dressings are based upon a normal dressing of dung as indicated above, but where a heavy application of farmyard manure has been given, i.e. 15 to 20 tons per acre, the crop should receive about 50 lb. of soluble P_2O_5 only. Dung should be ploughed in during autumn except in heavy-rainfall districts, and it is advisable not to apply farmyard manure on land infected with 'finger and toe'.

The latter disease is the most prevalent cause of failure of swedes and turnips but is only serious on soils which are lacking lime. Lime deficiency is therefore an extremely important factor in the cultivation of these crops, and 'finger and toe' is usually

a certain indication of the need for lime or chalk. On such soils, fertilizers which tend to increase soil acidity should not be used for the turnip crop until lime has been supplied. On the other hand, certain forms of phosphoric acid and nitrogen are relatively more effective under acid soil conditions and may therefore be used where lime cannot be given.

The turnip crop is not normally able to make efficient use of the amounts of nitrogen recommended for other root crops, and too much nitrogen occasionally lowers the keeping qualities of the roots. The nitrogen should be applied to the seed-bed and enough to bring the crop quickly to the thinning stage is all that is necessary. For normal soils ammonia nitrogen should be chosen, but on acid soils infected with 'finger and toe', nitrate nitrogen or cyanamide may be used. The crop is most responsive to phosphoric acid which in the main must be soluble, although in heavy-rainfall districts or on acid soils up to half the phosphate may be supplied in less available form. Potash is not nearly so important for turnips as for other root crops and on good soils is rarely required, particularly if dung has been applied for the crop.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Light, sandy, and chalk soils	25	75	50	1	3	2
Loams and heavy soils	30	90	..	1	3	..
'Organic' soils	..	90	60	..	3	2

Each pound of phosphoric acid may be expected to increase the yield on the average by about 1¼ cwt. of roots, provided nitrogen and potash are also available.

A ton of these crops removes approximately the following amounts of nutrients:

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Roots	5	3	7
Leaves	10	3	9

Kohl-rabi.

Although from the botanical point of view this crop is more closely allied to the cabbage than the turnip, from the farmer's standpoint kohl-rabi may be classified as a root crop. It succeeds better than turnips under dry soil conditions, and hence the effects of organic matter in relation to the soil moisture are of less moment than for other root crops. On the other hand, kohl-rabi is to be regarded as a 'heavier feeder' than turnips and on light soils a dressing of farmyard manure should be given if it can be supplied cheaply and if other organic residues are not ploughed in for the crop. The dressing of farmyard manure should be a medium one of about 10 tons per acre, together with fertilizers as indicated below.

As with all crops of the turnip and cabbage family, the heaviest yields of kohl-rabi cannot be secured from land seriously deficient in lime, but kohl-rabi is less affected by 'finger and toe' than are turnips and swedes. Consequently on soils infected with the disease, and where soil acidity cannot be rectified for turnips, the kohl-rabi offers a substitute of which advantage might well be taken on a wider scale than at present.

The basis of the fertilizer dressing must be phosphoric acid, but the crop can make better use of nitrogen than turnips; one-third of the nitrogen should be applied as a side-dressing after singling, except on 'organic soils'. Nitrogen may be given in either ammonia or nitrate form.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Light soils . .	30	60	60	1	2	2
Loams and heavy soils	45	70	45	2	3	2
'Organic' soils . .	20	80	60	1	4	3

Chicory.

Chicory only succeeds as a root crop on deep, free-working soils which are not subject to 'drying out' before the young plant is established. Consequently the supply of organic matter is important for this crop on light soils, where 10 to 12 tons of

farmyard manure per acre should be applied in autumn unless heavy crop residues are ploughed in. On 'organic' soils dung is not required nor is it necessary on heavy soils in good condition. Farmyard manure is probably best applied to the preceding crop rather than direct to chicory.

Nitrogen may be given both in the seed-bed and as a top-dressing after singling, the total dressing being divided equally between the two applications except on 'organic' soils where the top-dressing will generally be unnecessary. The phosphoric acid should be in soluble form.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Light sandy soils .	45	30	60	3	2	4
Good loams and clays	45	45	45	1	1	1
'Organic' soils . .	20	60	60	1	3	3

Carrots.

Carrots require deep, free-working soils, and on sandy or other open-textured soils the provision of organic matter is important if the crop is to be safeguarded from the effects of long periods of dry weather. Consequently, if abundant organic residues from the previous crop are not ploughed in, a good dressing of farmyard manure is desirable. Since fresh manure greatly encourages the development of 'fangy' and 'soft' roots, the dung should preferably be applied to the crop preceding carrots. Where this has not been possible, well-rotted farmyard manure should be ploughed in deeply in the early autumn, and 12 tons per acre is a suitable dressing, supplemented by fertilizers. On soils containing plenty of organic matter, or which do not suffer from drought, excellent crops can be grown without recourse to farmyard manure.

The lime status of the soil would not appear to be a matter of much importance in view of the types of soil on which carrots are usually grown, but there is little reliable information on the subject.

Nitrogen is frequently applied partly in the seed-bed and partly as a top-dressing after singling, but in view of the

desirability of discouraging surface rooting and 'blowing', it would appear preferable to apply all nitrogen in the seed-bed, and in either the nitrate or ammoniacal form. If a top-dressing be given it should be as nitrate, although soot is favoured in districts subject to carrot-fly attack. The phosphoric acid should be of soluble type and is of less importance than either nitrogen or potash; the latter may be supplied in any of the potash fertilizers. The fertilizers should be deeply harrowed into the seed-bed before sowing.

The manuring of 'bunching' carrots is dealt with in the section dealing with market-garden crops.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Proportions.*		
	lb.	lb.	lb.	N.	P_2O_5.	K_2O.
Light sandy and gravel soils . . .	40	40	80	1	1	2
Good loams . .	30	60	60	1	2	2
'Organic' soils . .	20	80	80	1	4	4

A ton of carrots removes the following amounts of plant nutrients: 4 lb. of nitrogen; 2½ lb. of phosphoric acid; 6 lb. of potash.

Parsnips.

The manurial treatment for parsnips is very similar to that recommended for carrots. Farmyard manure is very valuable in the absence of abundant organic matter in the soil, but the dung should be applied to the crop preceding parsnips. Too much organic material, however, encourages forking and 'soft heads'. The parsnip is susceptible to lack of lime, and for satisfactory crops the lime status of the soil must receive attention.

Potash is the most important of the other plant nutrients and the dressings recommended for carrots should be followed. The fertilizers should be deeply harrowed into the seed-bed before sowing, but on light soils part of the nitrogen may be reserved for side-dressings after thinning; for this purpose nitrate nitrogen should be used. Nitrogen may be used rather more generously on parsnips than carrots. A dressing of about

5 cwt. of common salt per acre is sometimes given after singling with the object of diminishing 'canker' or 'rust', which is looked upon as due to the splitting of the roots during a period of particularly rapid growth.

A ton of parsnips on the average contains about 6 lb. of nitrogen, 3 lb. of phosphoric acid, and 11 lb. of potash.

GRAIN AND SEED CROPS

Wheat.

Although heavy crops of wheat are usually obtained on organic soils, like all cereals it has less need of soil organic matter than the root crops. Nevertheless it is not an uncommon practice on the lighter wheat soils to apply a dressing of farmyard manure, but very rarely can this be economically justifiable. On such light soils, or where wheat is grown continuously, organic matter should be provided more cheaply by the ploughing-in of green crops or high, thick stubbles. In these circumstances nitrogen will usually be required in autumn for winter-sown wheat, but after clover or other legumes, roots or fallow, nitrogen should not be applied before spring.

Wheat cannot be grown without risk of partial failure on soils which are seriously deficient in lime, although wheat is not so susceptible to soil acidity as barley. Where an unsatisfactory 'plant' is experienced, an examination of the soil should be made to ensure that lime deficiency is not the cause.

Nitrogen is the dominant plant nutrient for wheat, phosphoric acid and potash under most circumstances in Britain having little influence upon yield. Where nitrogen is required in the autumn for the decomposition of crop residues, from 20 to 30 lb. per acre in the ammoniacal form should be harrowed in deeply before seeding. Where phosphoric acid and potash are required they also should be applied to the autumn seed-bed. Practically all wheat will need nitrogen in spring, but the time of application will depend upon the condition of the crop. Where the latter has wintered satisfactorily, the top-dressing of nitrogen should be applied during early May or towards the end of April on light, early soils. If, however, the plant has been thinned during winter the nitrogen should be given during February or early March with the object of encouraging tillering.

The manuring of spring-sown wheat should be on the lines

recommended for wheat after a straw crop, but for spring wheat the fertilizers should be applied to the seed-bed. On land in good condition part of the nitrogen may be withheld or applied later in spring if the crop receives a check.

Rates of Application per Acre.

	After a straw crop.			*After roots, fallow, or legumes.*		
	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Nitrogen.*	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.	lb.		
Light and chalk soils	50	30	45	30	..	..
Good loams and clays	50	30	..	30	..	..
'Organic' soils	..	45	45	..	..	..

Under average conditions each pound of nitrogen will give an increased yield of 14 lb. of grain and 20 lb. of straw.

One ton of wheat grain removes about 40 lb. of nitrogen, 20 lb. of phosphoric acid, and 13 lb. of potash; and a ton of straw about 10 lb. of nitrogen, 4 lb. of phosphoric acid, and 18 lb. of potash.

Barley.

In the cultivation of malting barley the organic matter in the soil is of much importance; good malting samples cannot be expected on soils containing much nitrogenous organic matter. For this reason, where malting quality is required, it is not desirable to precede barley with folded roots or to plough in large amounts of nitrogenous organic matter or farmyard manure. A cereal is the best precursor of malting barley in view of the great influence of early sowing upon quality and the detrimental influence of large amounts of nitrogen. Organic matter which has decayed in the soil and lost its nitrogen is, of course, valuable for its physical effects and its influence upon the moisture content of the soil.

Barley quickly suffers from any serious shortage of lime and satisfactory crops cannot be obtained on acid soils. On land which does not contain a good reserve of chalk a periodical liming is necessary to ensure good crops.

Nitrogen is the dominant factor in the manuring of barley, and when properly used there is no risk of lowering the quality of the sample. Nitrogen, however, should be taken up in the early stages of growth and should therefore be readily available. Phosphoric acid and potash in themselves have little influence upon either yield or quality in a mixed crop rotation where other crops receive complete manurial dressings. There is, however, some likelihood that the best results from nitrogen will not be secured on poorer types of soils unless phosphates and potash are also supplied, and in such cases it will generally be found that a complete fertilizer is the safest method of securing a good malting sample. On light and sandy barley soils, potash is definitely required. The phosphoric acid should be in soluble form, and the potash is probably best given as muriate or 30 per cent. salts. Phosphoric acid is also valuable in reducing the damage caused by attacks of gout-fly.

For winter-sown barley the phosphoric acid and potash should be applied before sowing and the nitrogen as a top-dressing during spring—preferably in March. The fertilizers for spring barley should be lightly harrowed in to the seed-bed just before sowing. Where winter barley follows a cereal, one-third of the nitrogen may be applied in the seed-bed.

Rates of Application per Acre.

	After cereals.			*After roots, dung, or legumes.*		
	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Nitrogen.*	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.	lb.		lb.
Light and chalk soils . .	30	30	60	30	..	45
Good loams . .	30	30	30	0–20	..	..

Where barley is undersown with clover, the fertilizer dressings should always include about 45 lb. of potash per acre for the clover.

For feeding-barley, the manuring may be confined to a spring dressing of 30 lb. of nitrogen per acre after roots, dung, or residues of temporary leys, &c., and on good-bodied soils. On

light soils after a cereal crop the following dressing is suitable: 45 lb. of nitrogen, 30 lb. of phosphoric acid, 45 lb. of potash.

On the average, each pound of nitrogen may be expected to increase the yield of grain by 14 lb. and the straw by 14 lb.

A ton of barley grain removes about 30 lb. of nitrogen, 18 lb. of phosphoric acid, and 13 lb. of potash, and a ton of straw approximately 12 lb. of nitrogen, 4 lb. of phosphoric acid, and 24 lb. of potash.

Oats.

Oats usually thrive better than other cereals on land containing much organic matter and are generally preferred after ploughing out long-term leys. An abundance of organic matter is, however, associated with great development of straw and an increased tendency to 'lodge'. In view of the higher feeding value of oat straw, 'lodging' is less serious than with wheat and barley, and in circumstances where 'lodging' is deemed likely, the oat crop may be cut early and made into hay. On light soils, or following a previous cereal crop, oats sometimes receive a dressing of dung, but it is very questionable if such practice is really economic.

The oat crop will flourish on soils which are moderately acid and, except for rye, is the most suitable cereal for lime-deficient soils. On extremely acid soils, however, the yield may be limited, or the crop even fail, as a result of lime shortage. On the other hand, the best yields are seldom obtained on soils with a large excess of chalk. A slightly acid soil appears to be most suitable.

Manuring is a comparatively simple matter, since seldom is anything beyond nitrogen required, and this is best applied in ammoniacal form in the seed-bed for spring oats. Where the crop follows another cereal on the poorer types of soil, the nitrogen should be supported by phosphoric acid and potash. On the other hand, in heavy-rainfall districts no nitrogen should be given to oats following a rich clover-ley or roots 'fed on'. For winter-sown oats following a cereal, one-third of the nitrogen may be given to the seed-bed and the remainder in the spring, i.e. as recommended for winter wheat.

For each pound of nitrogen an average increase of 16 lb. of grain and 27 lb. of straw may be expected.

Rates of Application per Acre.

	After a cereal.			*After roots, fallow, or legumes.*		
	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Nitrogen.*	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.	lb.		lb.
Light or chalk soils	35	35	50	30	..	30
Good loams and clays	30	30	..	25	..	..
'Organic' soils	..	45	30	..	..	..

A ton of oats removes 36 lb. of nitrogen, 15 lb. of phosphoric acid, and 11 lb. of potash, and a ton of oat straw 12 lb. of nitrogen, 4 lb. of phosphoric acid, and 33 lb. of potash.

Rye.

Rye may be grown satisfactorily on soils too poor or dry to yield satisfactory crops of other cereals. Consequently the soil organic matter is a point of little interest since rye will flourish on light, dry soils or on fens. It is also the least susceptible of the cereals to extremely acid soil conditions, and hence may be grown successfully on land with a high lime deficiency.

Where rye is grown for grain, manuring should follow the lines recommended for oats, but the dressings may be on a slightly smaller scale. Where the crop is grown for feeding in the green state, nitrogen only is required; this should be given at about 25 lb. per acre in early spring for autumn-sown rye, and in the seed-bed for the spring-sown crop.

For each pound of nitrogen the yield of grain will be increased by about 17 lb., of straw by 30 lb. The increase of rye cut or fed green will obviously chiefly depend on the stage at which the crop is utilized.

The following are the approximate amounts of nutrients removed per ton:

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Rye grain	40	20	13
Rye straw	10	4	20

Field Beans.

Beans are typically a heavy land crop, though good yields are also obtained on fen soils. Although beans respond to farmyard manure, excellent crops are obtained on these soils with fertilizers only, and since nitrogen is rarely, if ever, required, the application of dung to field beans is usually uneconomic.

The question of lime is particularly important in the cultivation of the bean crop and satisfactory results cannot be assured on lime-deficient soils. Slight acidity is not serious, but on soils which do not contain a good reserve of lime a periodical dressing should be given where beans are regularly grown.

The application of nitrogen for field beans is unnecessary, but both phosphoric acid and potash are required. Phosphoric acid should be applied in soluble form, and on heavy land which is inclined to acidity, high-soluble basic slag should be chosen. Potash may be given as kainit or low-grade salts on organic soils, but as muriate on heavy land. The fertilizers should be worked into the seed-bed before sowing.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
		lb.	lb.
Light loams	..	30	90
Heavy soils and clays . .	..	45	45
'Organic' soils . . .	..	60	90

The bean is a legume and able to assimilate nitrogen from the atmosphere, hence, despite the large amount removed by this crop, the soil is enriched in nitrogen upon the decay of bean stubble and roots. A ton of beans contains about 90 lb. of nitrogen, 27 lb. of phosphoric acid, and 30 lb. of potash, and a ton of the dry threshed haulm, including pods, about 16 lb. of nitrogen, 7 lb. of phosphoric acid, and 42 lb. of potash.

The manuring of vegetable beans is discussed in the section dealing with market-garden crops.

Field Peas.

Field peas are grown both for grain and in forage mixtures for cutting green, and are distinguished by their purple flower

from the white-flowered culinary peas which are also grown on field scale. This section is confined to the manuring of field peas grown for grain, the other peas are considered under forage crops and market-garden crops respectively.

The supply of organic matter in the soil is of little moment in the cultivation of field peas, and farmyard manure should not be given since it encourages haulm at the expense of pods and delays ripening. The pea thrives best on light loams and gravels and is less successful on 'organic' and heavy soils.

Although good crops can be obtained on slightly acid soils, failures must be expected on soils of less than pH 5. The best results are usually obtained on chalk loams, and the lime content of the soil must be carefully watched on sands and gravels where peas are grown. Where there is not an abundant reserve of lime, a light dressing of chalk or limestone is generally advisable before sowing.

The manuring is similar to that for field beans, but the pea can make fairly efficient use of the more insoluble forms of phosphoric acid, and hence part of this nutrient may be supplied in the cheaper, less available forms. On the soils on which peas are usually grown the low-grade potash manures may be used most safely.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
		lb.	lb.
Good loams	..	60	40
Light chalks and gravels . .	..	40	80

Since the pea is a legume it increases the soil nitrogen upon the decay of the crop residue, but like the bean removes fairly large amounts of phosphoric acid and potash. A ton of threshed peas contains about 80 lb. of nitrogen, 20 lb. of phosphoric acid, and 22 lb. of potash, and a ton of pea straw about 30 lb. of nitrogen, 10 lb. of phosphoric acid, and 22 lb. of potash.

Linseed and Flax.

Linseed is cultivated on a small scale in Great Britain for the seed and also for the fibre, which is made into flax for the fabrication of linen. The manurial treatment differs slightly

according to the purpose for which the crop is grown. It may be successfully cultivated on a wide range of soils, but the land must be clean and the crop should grow unchecked if high-quality fibre is to be obtained. Organic matter in the soil is therefore of value in dry districts in view of its beneficial effect during periods of drought, but abundance of organic nitrogen is likely to produce a coarse fibre. For flax, therefore, it is inadvisable to apply dung, and the crop is probably best grown after a root crop or a cereal, except on light soils where it may be taken after clover or even folded roots if they are cleared early.

Linseed thrives best on a soil well supplied with lime, and where the crop is regularly grown the lime content of the soil must receive attention if crop failures are to be avoided.

Nitrogen must be carefully applied for flax since excess reduces the value of the fibre, hence it is best applied as a top-dressing after weeding, and if the condition of the crop indicates it to be desirable. Phosphates and potash should always be applied for flax. Phosphoric acid increases the amount of fibre and encourages early ripening and should be applied in soluble form. Potash encourages taller growth with better-quality fibre and is best given as chloride. Both phosphates and potash should be harrowed into the seed-bed. Where the crop is grown primarily for seed, more nitrogen can always be used and may all be given in the seed-bed.

Rates of Application per Acre.

	Linseed.			*Flax.*		
	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Nitrogen.*	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.	lb.	lb.	lb.
Light soils	30	30	60	20	40	80
Heavy loams and clays	25	50	50	..	60	60
Soils rich in organic matter	..	40	80	..	45	90

A ton of linseed contains about 85 lb. of nitrogen, 32 lb. of phosphoric acid, and 25 lb. of potash, and a ton of the straw 26 lb. of nitrogen, 4½ lb. of phosphoric acid, and 24 lb. of potash.

Buckwheat.

Buckwheat is grown as a grain crop in this country only for pheasants, but it is also grown as a green manure crop or for sheep feed. It is easily grown on poor, light soils and on soils which are very acid.

Buckwheat seldom receives any fertilizer beyond a light dressing of nitrogen, but should be manured on the lines recommended for oats. It makes good use of insoluble forms of phosphate, and where grown for sheep feed or as a green manure crop particularly, buckwheat may receive mineral phosphate, &c., much of which is likely to be available to the following crop. The following fertilizer dressings are suggested:

Rates of Application per Acre.

	For Grain.			*As a Green Crop.*		
	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Nitrogen.*	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.	lb.	lb.	
Very poor land .	30	30	45	30	30	..
Ordinary soils .	30	..	..	25	..	..

A ton of buckwheat contains 40 lb. of nitrogen, 22 lb. of phosphoric acid, and 16 lb. of potash, and a ton of the straw about 21 lb. of nitrogen, 3 lb. of phosphoric acid, and 24 lb. of potash.

FORAGE CROPS

Cabbage.

Cabbages succeed best on heavy soils and on those containing a large proportion of organic matter, and respond well to dressings of farmyard manure. On good soils excellent crops may be secured without application of dung, but on lighter soils where other sources of organic matter cannot be provided a dressing of farmyard manure of 10 to 15 tons per acre is desirable.

Lime is important in the cultivation of the cabbage crop, which is very susceptible to 'finger and toe' or club-root disease. The best crops cannot be expected on land showing any pronounced lime deficiency, even where 'finger and toe' is absent,

and liming should be regarded as essential on soils showing any deficiency.

The crop is generally regarded as a heavy feeder, and since it is grown entirely for the leaf, the dominant constituent of the fertilizers required is nitrogen. The nitrogen should be in quickly available form, one-third applied in the seed-bed or before planting out, and the remainder in two side-dressings—usually at intervals of four to six weeks. For the side-dressings nitrate nitrogen should be used in most circumstances.

Phosphoric acid is necessary and part should be given in quickly available form, but since the cabbage is relatively efficient in utilizing the insoluble forms of phosphoric acid, part may be supplied as bone manures, guano, or mineral phosphates, where these are cheaper than more soluble forms. All phosphatic manures should be applied before sowing or planting out.

On good-bodied soils, particularly where dung has been given, little effect may be expected from potash, but on the light and 'organic' soils potash is desirable and is probably best applied as kainit or low-grade salts. Potash is also more important for late autumn cabbage than for summer varieties in view of its effects upon frost resistance. Common salt can be used up to 3 cwt. per acre to replace an equal weight of low-grade potash manure. Part of the potash manures and the salt may be applied as side-dressings along with the first application of nitrate nitrogen, but the bulk of the potash is probably best given before sowing or planting out.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Heavy soils and clays . .	75–100	75	..
'Organic' soils . . .	50	75	75
Light loams	60	60	60

A ton of cabbages contains about 8 lb. of nitrogen, 3 lb. of phosphoric acid, and 7 lb. of potash.

Rape.

The amount of soil organic matter is of little interest in so far as the cultivation of rape itself is concerned, but the crop

is usually grown with the object of increasing the soil humus, either by ploughing-in or folding with sheep. Rape is a quick-growing crop which requires no organic manure, and is often sown partly with the object of conserving the nitrogen accumulated in the soil during summer.

The crop thrives best on soils with a good reserve of lime and, like all varieties of the turnip and cabbage family of plants, rape is subject to 'finger-and-toe' disease on lime-deficient soils.

Where rape is sown in spring as a nurse crop for clover seeds on good soils, no nitrogen should be applied, and this also holds where the crop is grown after an early summer fallow on fertile soils as a preparation for an autumn-sown cereal. In other circumstances a moderate amount of nitrogen may be applied in the seed-bed as indicated below, together with easily soluble phosphates. Potash will only be required where the rape is sown as a nurse crop for clover seeds, and in these circumstances the rape should not be manured but the clover should be treated as recommended later.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	
Light, sandy, and chalk soils .	20	30	..
Clays and poor heavy loams .	20	40	..
'Organic' soils . . .	..	40	..

A ton of rape contains approximately 10 lb. of nitrogen, 3 lb. of phosphoric acid, and 8 lb. of potash.

Mustard.

White mustard is closely akin to rape and requires similar conditions and treatment, but it is never used as a nurse crop. On soils in reasonably good heart, or where grown after a summer fallow with the object of conserving soil nitrates, it should require no fertilizer; in other circumstances it may be treated on the lines indicated for rape.

Marrow-stem Kale.

This crop is a gross feeder and makes very good use of farmyard manure of which dressings up to 12 or 15 tons per acre

are likely to be economic where supplies are easily available. On heavy soils, or those with a good reserve of organic matter, excellent crops can be secured without any dung, but the following recommendations are intended where dung is given. If farmyard manure is not applied, the potash and nitrogen may be increased by about 30 lb. per acre.

Marrow-stem kale is not so susceptible to 'finger-and-toe' disease as are turnips and cabbage, and it may therefore be expected to thrive better than these crops on lime-deficient soils. Nevertheless the best yields cannot be expected on soils with a serious lime shortage.

Few crops give larger responses to nitrogen, and exceedingly heavy dressings can as a rule be profitably employed. The nitrogen should be applied in readily available form, and divided into a seed-bed application and one or two side-dressings at approximately monthly intervals.

The phosphoric acid should be given in the seed-bed and part should be readily available to encourage quick establishment, but as kale is capable of making good use of the insoluble types of phosphatic fertilizers up to half the phosphoric acid may be given in such cheaper form.

Potash, where required on heavy soils, should be applied as chloride, but on other soils the salts and kainit are equally suitable if they can be applied at no greater cost.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Light, sandy, and chalk soils .	75	40	80
Good loams and clays . .	100	60	60
'Organic' soils . . .	50	50	75

A ton of kale removes from the soil about 10 lb. of nitrogen, 2 lb. of phosphoric acid, and 9 lb. of potash.

Thousand-headed Kale.

This crop is treated on the lines of marrow-stem kale but is fertilized on a more moderate basis. It responds well to farmyard manure but can be grown satisfactorily with fertilizers alone. It is also more resistant to 'finger and toe' than the

majority of crucifer crops, but succeeds best on soils well provided with lime. Where dung is plentiful a light dressing of some 10 tons per acre may be given with nitrogen and phosphates as indicated below. Without farmyard manure the complete dressings shown in the table should be applied and the nitrogen may be increased by 25 to 50 lb. per acre.

Of the nitrogen, about 25 lb. should be given in ammoniacal form in the seed-bed and the balance as a nitrate side-dressing after thinning. Part of the phosphate may be in insoluble form and all should be applied before sowing.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Light, sandy, and chalk soils .	50	50	50
Good loams and clays . .	60	60	. .
'Organic' soils . . .	25	50	50

Legume and Cereal Mixtures.

These crops include various mixtures of barley, oats, rye, wheat, buckwheat, and vetches, beans, peas, and clovers, the species grown and the proportions in the seed mixtures being varied to suit local requirements. Such mixed crops present a fundamental difficulty in deciding upon the manner of manuring since the legumes rarely require nitrogen, and if this be given for the cereals the legumes are likely to be checked by the vigorous growth of the cereals. The extent to which nitrogenous fertilizers are to be used will thus depend upon the character desired in the crop when it is harvested, and the influence of soil and climate upon the early development of the various component species of the mixture.

The effect of nitrogen is to encourage the cereals at the expense of the legumes in the mixture and generally to produce a heavier total crop than if nitrogen were not given, but the heavier crop will be of more carbohydrate character, i.e. the proportion of protein will be decreased although the total amount of protein produced per acre is not likely to be seriously diminished. Naturally the converse is true, viz. that where nitrogenous fertilizers are withheld and the leguminous plants

experience less competition from the cereals, the crop will contain a higher proportion of protein, but the total weight produced per acre may be no greater, and the weight of carbohydrate food yielded per acre is likely to be less.

Other circumstances have also to be considered apart from the nature of the final feeding value of the crop, and of these the most important is the effect of the nature of the mixture upon the facility with which it may be harvested. For example, in a mixture of peas, vetches, and oats, if the proportion of oats be seriously reduced the difficulties in handling the crop are greatly increased, particularly if it is made into hay.

When the grower has decided upon the character of the crop he wishes to secure, it is obvious that under most conditions the application of nitrogenous fertilizers must be delayed as late as possible in order that nitrogen may be used only should it be necessary to counterbalance the effects of soil and climate. Since, however, the nitrogen then has to be applied as a top-dressing, its application cannot be delayed until the soil is wholly covered by the crop, and hence nitrogen can only be used for a corrective influence upon both quality and quantity in the very early stages of the crop.

The nitrogen recommended in the following dressings should thus be applied as a top-dressing when the crop is through, while the phosphatic and potassic manures are best given in the seed-bed.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Light soils, gravels, chalks .	0–50	30	30
Good loams and clays . .	0–50	45	. .
Soils rich in organic matter .	0–30	45	30

Under many circumstances the less soluble forms of phosphoric acid fertilizers may be used for forage mixtures; finally unsatisfactory development of the legumes may be experienced on lime-deficient soils.

Italian Rye-grass.

This rapidly growing plant is often sown as a pure seeding, frequently as a catch crop, and is particularly valuable for the

production of very early spring grazing or for cutting later in the season. It does particularly well on moist soils and under sewage irrigation. Although it responds to dressings of farmyard manure, the latter can generally be used to better advantage elsewhere on the farm. Except on poor and light soils, only nitrogen is required in the manuring of Italian rye-grass. Nitrogen may be applied in any form and the crop is particularly responsive and suited to dressings of liquid manure. Since the plant is hardy, liquid manure may be applied at any time of the year and, except in an extremely severe winter, rapid response will be obtained.

Care must be observed in the application of liquid manure during sunny weather, when scorching is liable to occur even if the liquid manure is well diluted; applications during summer should as far as possible be made during rainy weather. Nitrogen should be applied in several dressings during the year, and on soils not normally liable to drought, up to 100 lb. of nitrogen per acre may be given. A dressing in the late autumn of the seeding year at 25 to 30 lb. of nitrogen per acre will provide grazing at the beginning of the year. An application in February will stimulate early growth in spring, and subsequent dressings may be given as required during late spring and summer. Each application should supply 25 to 45 lb. per acre of nitrogen according to the time of year and whether the herbage is to be grazed or mown.

On light land in poor condition, an application of 30 to 45 lb. of potash as salts or kainit should be given during the autumn of the seeding year, though potash should be unnecessary if liquid manure is available for the crop.

A ton of green rye-grass removes about 12 lb. of nitrogen, 5 lb. of phosphoric acid, and 17 lb. of potash.

Maize.

Maize in this country is grown only as a forage crop and green vegetable; as a grain crop it is quite unreliable. It produces a heavy yield of green foliage and requires liberal manuring. Satisfactory crops can be secured on soils not seriously deficient in moisture, but on light land the crop responds well to a dressing of farmyard manure ploughed in early.

Soil acidity is not an important factor in the cultivation of

maize, and this crop will thrive on a wide range of lime-deficient soils.

The following recommendations are based upon a dressing of 10 to 12 tons of farmyard manure per acre on light soils; if dung is applied on good-bodied soils the nitrogen should be reduced by one-third. If no dung is given on light soils the nitrogen should be increased by 25 lb. per acre, and 50 lb. of potash added.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	
Good loams and clays . .	75	45	..
Light soils	45	30	..

Half the nitrogen should be applied along with the other fertilizers before seeding, and half as a side-dressing when inter-row cultivations are completed.

A ton of green maize fodder contains about 7 lb. of nitrogen, $2\frac{1}{2}$ lb. of phosphoric acid, and 8 lb. of potash.

Vetches.

Unless grown for seed, vetches are taken as either a winter or summer catch crop which will thrive on a wide variety of soils, provided they are not very seriously lacking in lime. Some difficulty in securing establishment of the plant may be experienced on soils where vetches have not previously been grown. Such a condition rarely arises, however, and may be remedied by broadcasting a few cwt. per acre of soil from a field where vetches have been grown successfully.

Although grown for the leaves, the crop does not require heavy dressings of nitrogen since as a legume it does not entirely depend upon the nitrogen compounds in the soil. Spring-sown vetches are more in need of nitrogen than autumn-sown, though the latter often respond to an early spring dressing. Phosphoric acid should be applied in soluble form and potash may be given as kainit on light soils.

The phosphates, and potash where given, should be applied to the seed-bed, and the nitrogen as a top-dressing when the plants are 2 or 3 inches high.

Rates of Application per Acre.

	Nitrogen.	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.
Heavy soils and loams . .	25	60	..
Light sands and chalks . .	25	45	45
'Organic' soils . . .	..	60	60

A ton of green vetches contains about 11 lb. of nitrogen, 3 lb. of phosphoric acid, 11 lb. of potash, and 12 lb. of lime.

Trifolium.

This winter catch crop rarely receives manurial treatment, though it responds to fertilizers and should be manured on the lines recommended for winter vetches. The phosphates and potash should be applied to the seed-bed. Satisfactory crops cannot be expected on land seriously deficient in lime.

Lupins.

This legume is commonly grown on poor, sandy soils as a catch crop either for sheep feed or for ploughing-in green. Lupins seldom receive any direct manurial treatment and will rarely require anything beyond an application of phosphates. The crop is chiefly used to increase the amount of soil organic matter and is not difficult to establish on lime-deficient soils. It may, however, suffer from extreme acidity, and on the other hand an excess of lime is undesirable. Under most circumstances an application in the seed-bed of phosphoric acid, at about 45 lb. per acre, will supply all the fertilizer required. The crop is fairly efficient in utilizing insoluble forms of phosphoric acid.

Lucerne.

This extremely valuable leguminous forage crop thrives on deep, well-drained soils when once it has become established. A certain amount of organic matter is valuable during the early stages of the plant, and on light soils a dressing of farmyard manure ploughed in during the autumn before seeding, or applied to a preceding root crop, greatly assists the establishment of the young lucerne. It is rarely advisable to apply dung

to the established crop since such an application is more likely to benefit weeds than the lucerne.

The lime content of the soil is particularly important since the crop will not withstand acid soil conditions. On lime-deficient soils a heavy dressing of chalk should be given during the winter before sowing, and from 10 to 20 cwt. per acre should be applied every third year subsequently.

Lucerne is able to make use of atmospheric nitrogen and does not respond to nitrogenous fertilizers to nearly the same degree as the majority of other forage crops. On poor soils, where a pure sowing of lucerne has been made, a light application of about 25 lb. per acre of nitrate nitrogen may be given during the first and second years, provided the land is clean. In other circumstances it is generally preferable to withhold nitrogenous fertilizers from this crop.

Phosphoric acid is the most important of the plant foods for lucerne, and the bulk of it may be given in insoluble form. For the first year or two it is, however, advisable to apply a soluble form of phosphoric acid. The first dressing will be incorporated into the seed-bed before sowing and subsequent dressings may be harrowed in every other year.

Potash is essential on light soils and not only increases the annual yield but usually prolongs the duration of the stand. The first application will be given to the seed-bed, and those of succeeding years will be applied in conjunction with the phosphatic fertilizers every second year.

Rates of Application per Acre.

	Phosphoric Acid.	*Potash.*
	lb.	lb.
Heavy soils	80	. .
Light, sandy, and chalk soils .	60	60

Difficulty in obtaining establishment of lucerne is usually encountered on land which has not previously grown the crop, and in such circumstances it is essential to sow seed which has been inoculated with the bacillus associated with lucerne.

A ton of green lucerne cut at the flowering stage contains about 15 lb. of nitrogen, 3 lb. of phosphoric acid, 10 lb. of potash, and 20 lb. of lime.

Sainfoin.

This leguminous forage crop thrives on dry, warm soils, particularly if the underlying subsoil is deep and open. It is chiefly grown on light, chalky soils and a dry environment is most suitable, hence little organic matter in the soil is required. If the preceding root crop has received farmyard manure, it will not be necessary for sainfoin, but in other circumstances a dressing of about 10 tons per acre may be ploughed in during the autumn before sowing to assist in establishing the seedlings.

Sainfoin will thrive on good-bodied soils provided the subsoil is an open one and the soil contains plenty of lime. Lime is most important, and satisfactory establishment and good yields cannot be expected on soils showing any shortage.

The manuring of sainfoin should follow that recommended for lucerne, but some distinction is necessary between Common Sainfoin, which is perennial, lasts five years or more, and is suitable for grazing, and Giant Sainfoin, which is a heavier yielder more suitable for hay and occupies the land for one year or, rarely, two years.

Nitrogen may be applied to Giant Sainfoin in early spring, but nitrogenous fertilizers are undesirable for Common Sainfoin since they tend to encourage weeds more than the crop. Both varieties should receive phosphoric acid and potash in the seed-bed, and the Common Sainfoin should subsequently receive similar dressings every other year, applied during autumn or winter.

For the seed-bed application a high-soluble form of phosphoric acid should be given, but later dressings for Common Sainfoin may consist of less available phosphatic fertilizers.

Rates of Application per Acre.

	Giant Sainfoin.			*Common Sainfoin.*		
	Nitrogen.	*Phosphoric Acid.*	*Potash.*	*Nitrogen.*	*Phosphoric Acid.*	*Potash.*
	lb.	lb.	lb.		lb.	lb.
Light and chalky soils . .	25	45	60	..	60	80
Good loams . .	..	60	30	..	60	30

Clovers.

The group of plants referred to as clovers by farmers in Great Britain includes Broad Red Clover, Late-flowering Red Clover, Dutch White, Wild White, Alsike, and Yellow Suckling Clover, as well as Yellow Clover or Trefoil. Many of them are seldom sown as a pure seeding but are included in seed mixtures of various clovers and grasses for temporary and permanent leys. The manuring of such mixtures will be dealt with later, but for all the pure sowings of any of the clovers the same fertilizer treatment is suitable, irrespective of whether they are primarily hay or pasture species.

In the cultivation of clovers the amount of organic matter in the soil is of small account, although soils containing much humus are usually most subject to clover sickness. Animal manure is not required for the clovers, but an early spring dressing of dung often has a beneficial effect on the early development of the plant. The dung shelters the young plants and provides a stimulus, but if the crop is weedy the weeds are likely to gain more benefit than the clovers. On most farms, however, there are usually better uses for farmyard manure than applying it to the clover crop.

Any serious deficiency of lime in the soil has an unfavourable influence upon the establishment and growth of clovers, though all kinds are not equally susceptible. The red clovers invariably suffer most from pronounced soil acidity, and alsike least. Often when a good plant is obtained which fails to stand through the first season the cause is lack of lime. On soils which are deficient, and where trouble has been experienced they should always be examined for lime shortage, an application of 1 to 2 tons of lime or chalk should be harrowed in during the winter or early spring before sowing.

For pure sowings of clovers, and clovers for seed purposes, nitrogenous fertilizers are not required. Phosphatic manures are essential, the type chosen depending upon the soil and other environmental factors. Potash is also usually required, and any form is suitable, provided precautions are observed in application to avoid scorching. Young clover seedlings may be seriously damaged as a result of applying potash fertilizers under unsuitable conditions. Both phosphatic and potassic manures should

be harrowed into the seed-bed before sowing, and, where applied as a top-dressing to an established clover crop, potash manures must be broadcast only when the foliage is dry.

The following dressings are recommended for seed-bed application or on established crops for hay or for seed.

Rates of Application per Acre.

	Phosphoric Acid.	*Potash.*
	lb.	lb.
Heavy soils and good loams .	60	30
Light soils and chalks . .	45	45
Peaty soils and black sands .	60	60

A ton of green clover foliage contains about 3 lb. of phosphoric acid and 12 lb. of potash.

GRASSLAND

There are many types of grassland used for a wide variety of purposes. Permanent grass for grazing or hay alters greatly with changes in environment; temporary leys are subject to the same influence and differ also according as they are used for grazing, hay, or both. Obviously all local variations in soil, climate, and kind of farming cannot be considered in detail. In most circumstances manuring is definitely of secondary importance to management, and consideration of manuring has therefore been limited to a broad review of the principal types of grassland.

Permanent Pasture.

At the outset it cannot be too strongly emphasized that manuring alone will not necessarily improve a pasture or maintain grazing land in good condition. Fertilizers cannot make up for lack of good management in those other factors, proper grazing, cultivations, drainage, and mowing, all of which exert a great influence upon the quality and productivity of pasture land. The effect of fertilizers is in fact not nearly so great as that of these other items, and the type of manuring adopted must be decided almost entirely by the extent to which the other factors are operating.

The feeding value of a pasture is primarily determined by the soil, climate, the species of plants present, and the stage of growth at which they are eaten, though the yield and quality of each and every desirable species can be improved by good management and manuring. Conversely, the growth of any species may be curtailed by the treatment given to the pasture; the key to pasture management is competition amongst the different species of pasture plants. By applying treatment known to favour some species or to discourage others the character of a pasture is largely a matter of control. Space cannot be given to a consideration of the effects of too much water in the soil and the improvement brought about by drainage, but it need scarcely be pointed out that the best-quality pasture plants never thrive where the soil is waterlogged. Moreover, a detailed review cannot be made of the effects of times of grazing upon the different species of grasses and clovers or upon the correct use of the mowing-machine and harrows. Briefly, no pasture should become sod-bound with a thick, matted turf; where the latter exists it should be destroyed by repeated harrowings with sharp spike harrows in conjunction with a dressing of lime before fertilizer treatment begins. Grazing should never be severe in both early spring and autumn for two years in succession; the most valuable species of pasture grasses start growth early and continue late in the season, and hard grazing during these periods severely checks such grasses at the expense of the bents and other less desirable species. The latter type start growth late in the season and make growth rapidly, so that in order to curtail their development pastures should be kept closely grazed during late spring and early summer. At this time of the season, if the stock cannot keep the herbage in check, the grazing must be supplemented by the mowing-machine. The amount of clover present in a pasture is almost entirely a function of the management of grazing, and the fertilizers applied have in comparison relatively little effect. Where the grasses are permitted to become long and thick the clovers suffer greatly from shading and are soon crowded out; even a single season of such management will result in great diminution of the clovers. On the other hand, continuous close grazing frequently results in too great a development of clovers with the result that such a pasture produces little herbage in the early

and late season. Briefly, nitrogenous fertilizers encourage the grasses more than the clovers, and with phosphatic fertilizers the reverse holds true. Potash is required on very light soils, more particularly for the development of clovers, and periodical applications of lime are necessary on markedly acid soils.

Nitrogenous fertilizers are of most value on pasture land for stimulating early growth at the beginning of the grazing season. This 'early bite' cannot, however, be secured merely by the indiscriminate use of nitrogen. Obviously species of grasses capable of early growth must be present in the pasture and they must have been grazed properly during the previous season to fit them for 'early bite' treatment, i.e. hard grazing must have been avoided during the previous early spring and autumn. Nitrogenous fertilizers may be similarly used at any time during the grazing season when it is desired to increase rapidly the amount of herbage on a pasture field. Nitrogen, however, should only be used where adequate control of the herbage can be exercised through the live stock and mowing-machine, and it should not be forgotten that the bigger yield of herbage secured from the use of nitrogenous fertilizers means a greater removal of phosphates, &c., from the soil. Nitrogen in the organic form is applied to grazing land through the excreta of live stock and occasionally by a dressing of farmyard manure, but the latter can only be advisable on the lightest soils and in dry districts. For 'early bite' treatment, ammonia nitrogen is generally preferable, and for later-season use there is little to choose between nitrate and ammonia nitrogen. The early spring dressing should be applied about the time the first signs of growth are expected and should supply 30 to 40 lb. of nitrogen per acre; applications later in the season should consist of 20 to 30 lb. per acre.

Apart from the rather specialized use of nitrogen, the manuring of grazing land is largely a question of supplying phosphates. Pasture land already well managed may show little apparent result from phosphatic fertilizers, but on poor soils or pastures which have been mismanaged, phosphates provide the basis for the initial improvement and frequently give striking effects. Even where the herbage may give no obvious indication of improvement, its feeding value is likely to be enhanced by phosphatic dressings. Water-soluble phosphoric acid is generally

the form most certain in action, but a basic slag in which the phosphoric acid is highly soluble will give almost equally good results. On heavy and organic soils which are inclined to be acid, and more especially in districts of heavy rainfall, the more insoluble forms of phosphate are generally effective on grassland but are rarely so good as the more available forms of phosphoric acid. Phosphatic fertilizers may be applied to permanent grassland at any period of the year and at the rate of from 20 to 30 lb. of phosphoric acid per acre per annum, according to the manner and intensity of grazing. Most farmers in this country apply the phosphatic fertilizer once in three years, and there would seem to be evidence in favour of applying an initial heavy dressing of 100 to 150 lb. of phosphoric acid per acre on poor pastures, but on good grassland the more frequent and lighter applications are usually preferable.

As a rule potash is necessary only on the lighter classes of soil and is generally most suitably applied in one of the lower-grade potash manures. Large amounts of potash are not removed from grazing land, but potash is often required on sandy or 'organic' soils for satisfactory establishment of clovers. Potash may be applied at any time during autumn, winter, or early spring, and, like phosphates and lime, should always be harrowed in, except on light soils with a poor, thin sward. To pastures on sands, gravels, and chalks where clover does not thrive, a dressing of potash at the rate of 50 lb. per acre should be given. Where this is effective the dressing should be repeated every other year, or even annually where grazing is intense and a heavy yield is maintained by a satisfactory moisture supply.

Rough Hill and Moorland Pastures.

This class of grazing land embraces a wide variety of soils and climatic conditions, and human neglect; under many circumstances the last is the dominant factor since climatic and soil environment are often suitable for many species of valuable pasture plants, and in such cases great improvement can be secured. On the other hand, sandy heaths in low-rainfall districts and land annually subject to water submergence for lengthy periods cannot be regarded as likely to repay expenditure on fertilizer treatment. Where moisture supply is sufficient the natural herbage of poor and neglected grassland consists

largely of bents, fine-leaved fescues, and other bristle-bladed grasses, sedges and rushes, heather and gorse.

For introducing and establishing pasture plants more valuable than the indigenous types, manuring alone does not suffice. Fertilizers must supplement various forms of mechanical treatment, primarily designed to remove the bulk of existing matted vegetation so that air, water, and fertilizers may penetrate the soil proper. Such measures include cutting and cleaning drains, burning and cutting of herbage, drastic harrowing with sharp and heavy harrows, and re-seeding in conjunction with disk harrowing or even ploughing.

Very often, but not invariably, liming is a necessary preliminary to any fertilizer treatment, and as a general rule quicklime is the most suitable type to apply, since not only is its caustic action valuable, but haulage costs are usually an extremely important item in reclamation of poor pastures. Where previous experience is not available, the necessity for lime will be indicated by the natural herbage and the climate, lime being more important in districts of heavy rainfall than in others. The degree and rapidity of improvement desired must also enter into the decision upon the advisability of liming, since some improvement under any circumstances can be obtained without lime. The amount of lime initially applied, which may be from 1 to 3 tons of quicklime per acre, will also be subject to the same considerations.

In poor pastures, which are likely to repay expenditure upon amelioration, there is generally a superabundance of organic matter so that farmyard manure is not required and indeed quite apart from the cost of application it is generally undesirable. Inorganic nitrogen, however, is frequently economical, partly to assist the decomposition of organic matter and to provide plant food for the more productive species of grasses it is desired to establish. Nitrogenous fertilizers supplying some lime are preferable under these conditions and should provide about 25 lb. of nitrogen per acre, applied in spring after the winter's preparation of mechanical treatment and liming.

Phosphatic fertilizers form the basis of fertilizer improvement of poor pastures and heavy initial applications are necessary, since long neglected pasture soils are invariably depleted of available phosphoric acid. Practically all forms of phosphates

will bring about considerable improvement but a high-soluble basic slag is usually most satisfactory, especially where no lime has been applied. In high rainfall districts, ground mineral phosphate usually gives good results on poor pastures and under these conditions may be substituted for basic slag for the first dressing. In drier districts and where lime has been applied, water-soluble phosphoric acid will give better, and generally more rapid, results than other forms. The initial dressing of phosphoric acid should provide from 60 to 90 lb. of phosphoric acid per acre and should be applied after thorough mechanical treatment.

Applications of potash fertilizers more rarely lead to visible improvement of neglected hill pastures and in the early stages of reclamation on good bodied soils, potash should only be used where local experience has demonstrated its necessity. On light soils, after the first or second year of improvement, a dressing of low grade potash manures such as salts, kainit, or flue dust, supplying about 60 lb. of potash per acre can be tried if clover development is not already satisfactory.

Reclaimed pasture should subsequently be treated on the lines recommended in the previous section for ordinary permanent pasture.

Permanent Hay.

On permanent grass annually mown for hay an occasional dressing of farmyard manure is beneficial, particularly on the lighter types of soil, but on the other hand heavy yearly applications may engender deterioration of the sward. A dressing of 10 to 15 tons of farmyard manure per acre every third or fourth year is desirable, preferably applied in early spring. No other manuring is necessary during the year in which dung is applied, but in other years from 25 to 50 lb. of nitrogen per acre should be given in spring. Either ammonia or nitrate nitrogen is equally suitable under most conditions, nitrate being preferable on soils deficient in lime. During one of the years when no dung is given, meadows should receive phosphatic fertilizers supplying about 20 lb. of phosphoric acid per annum. Thus, if the phosphatic dressing be given every third year it should provide about 60 lb. of P_2O_5 per acre. Hay land is more responsive than pasture to potash, except where farmyard manure is applied annually. With a proper system of manuring combining both

dung and fertilizers, meadows on all but heavy clay soils should receive potash at a rate equivalent to about 20 to 30 lb. per acre per annum.

Additional nitrogen up to 20 to 30 lb. per acre may be applied after the first cut where it is desired to secure a second crop of hay or abundant aftermath grazing. Aftermath should not be heavily and continuously grazed in autumn, and if heavy crops are required, spring grazing of meadows must be discontinued in early spring. On soils which do not contain adequate reserves of lime an application equivalent to about 2 tons of carbonate should be given to meadows every fourth or fifth year, but if basic slag is used the lime may be reduced.

A ton of meadow hay contains about 35 lb. of nitrogen, 10 lb. of phosphoric acid, and 35 lb. of potash.

Temporary Leys.

Temporary leys embrace many mixtures of the various species of grasses and clovers and extend from one to three or four years' duration. A one-year ley should be manured as recommended for clover or for rye-grass according to which plant forms the bulk of the seeding.

Two-year clover-leys which are to be mown during the first year, should receive about 30 to 45 lb. of soluble phosphoric acid per acre. This is best applied in the seed-bed, but alternatively may be given during the autumn of the seeding year or early in the following spring. On chalks, fen, or light soils a similar amount of potash should be applied with the phosphatic manure. No further manuring should be necessary, except where early grass is desired for grazing during the second year and for which 20 to 30 lb. of ammonia nitrogen per acre should be applied in early spring. If clover has not succeeded and the herbage consists principally of grasses, nitrogen should be applied in spring for the first year's hay crop, in addition to the phosphates and potash recommended above. For this purpose from 25 to 50 lb. of nitrogen per acre should be applied, the heavier dressing being given where moisture conditions are conducive to heavy yields. The nitrogen should not be applied nor the crop cut for hay if it is desired to encourage the clovers; where the latter course seems justifiable the 'seeds' should be carefully grazed in the first year.

All leys of three or more years' duration may be regarded as one class, since after three years a ley may be treated as permanent grassland. Wild white clover is an important factor in the establishment of long term leys, hence the treatment during the first year must not result in the clover being crowded out. Phosphoric acid and potash should be applied as recommended for two-year 'seeds', but for longer leys the amounts per acre should be increased by about one-half. Nitrogen should only be given in the spring of the first year if the herbage is to be grazed or a strong stand of clover has been obtained. The nitrogenous dressing should never greatly exceed 25 lb. nitrogen per acre, and none should be given unless the clovers are vigorous. As outlined at the beginning of this section the grazing and mechanical treatment generally have a greater influence than manuring upon the species which become established. The lime status of the soil greatly affects the development of young seeds, and on lime-deficient soils an application in some form should be harrowed into the seed-bed before sowing grass and clover seeds. After the third year, temporary leys should be treated on the basis recommended for permanent pasture or for meadow, according to the purpose to which the ley is devoted.

MARKET-GARDEN CROPS

This category includes a wide range of crops which are grown for human consumption and are ready for sale to the consumer immediately they are harvested. They may be dispatched direct from the field to the distributor without any processing beyond that of cleaning, grading, and packing. For convenience of considering the manurial treatment of market-garden crops, they may be divided into the following classes:

1. Uncooked vegetables or salads.
2. Cooked vegetables:
   (*a*) Green.
   (*b*) Roots.

Salad Crops.

Many of these crops are grown from transplanted seedlings as well as from seed drilled on the permanent site of the crop. Where special seed-beds are cultivated for raising seedlings their

manurial treatment will differ from that of the field where the plants are grown to maturity. In the seed-bed, robust and slowly grown seedlings with well-developed root systems are desired. Such plants can be transplanted without being seriously checked and few will fail to establish themselves under normal circumstances. Quickly grown, forced seedlings or those which have become 'drawn' are never satisfactory and are very difficult to establish.

For the seed-bed a soil of open, friable texture is required in which seedlings can root freely and which drains easily and quickly. Where water can be provided as needed, organic matter is not so essential for the seed-bed, and a large amount in the soil is generally undesirable provided the soil is of open texture. A high proportion of organic matter tends to produce quickly grown, tender seedlings and encourages damp conditions favourable to mildew, and other harmful soil fungi.

The soil of the seed-bed must be well supplied with lime and should be frequently tested or receive an annual dressing of 4 to 6 cwt. per acre of hydrated lime to ensure that the soil does not become acid.

The chief fertilizer requirement of the seed-bed is phosphoric acid, potash is of less importance and nitrogen must be used with much circumspection. Phosphoric acid is probably best applied in two forms, the one water-soluble in superphosphate and the other in either a bone manure or ground rock phosphate. Equal amounts of the two types of phosphoric acid should be given and together should supply dressings equivalent to 60 to 90 lb. of phosphoric acid per acre per annum. The greater rate will be used on heavier soils and where conditions are not of the best. Potash for seed-beds should be applied in the form of sulphate of potash since in this form there is least risk of damage or check to the seedlings. The dressing should supply from 30 to 60 lb. of potash per acre per annum, and application should be made together with some of the phosphatic dressing a week or two before sowing seeds but preferably in the autumn.

For the raising of seedlings it may be taken as a general rule that very little nitrogen is required and that sufficient is likely to be available in the seed and in the soil. Where only a moderate amount of organic matter is present in the soil, however, a little additional nitrogen is desirable, but in order to lessen the

possibility of harmful effects on the seedlings the safest course is to apply the nitrogen in an organic form. The animal by-products, blood meal, hoof and horn meal, meat and bone meal, and fish meal, are suitable, since the nitrogen in these materials becomes fairly easily available, but as it does not readily become soluble there is small risk of injury to the seedlings, except, of course, through causing too rapid growth if applied too heavily. These fertilizer materials should be worked into the seed-bed a few days before sowing and should be applied at a rate supplying from 20 to 30 lb. of nitrogen per acre per annum. It will be found most satisfactory to give these nitrogenous manures in two or three dressings during the year rather than in one heavy annual application.

Soot is frequently used for top-dressing seed-beds with the principal object of discouraging slugs and wood-lice, &c. If this is a normal practice it must be remembered that soot contains from 3 to 5 per cent. of nitrogen in very readily available form, and it may therefore be desirable to reduce the amounts of other nitrogenous materials applied to the seed-bed. Dusting with a high grade hydrated lime is also valuable from time to time in checking insect and slug attacks and for preserving a healthy soil.

Celery.

The heaviest crops of celery are grown on deep, free-working soils containing an abundance of organic matter. Celery is a gross feeder and also demands a soil well supplied with moisture throughout the growing season. Hence, except on fen soils, heavy applications of organic matter should be incorporated in the soil for celery. Green crops may be grown and ploughed in, and up to 25 tons per acre of farmyard manure can be given with advantage. Organic matter in any form should be ploughed in deeply in autumn or early winter, or if well rotted, may be incorporated with the soil in the bottom of the trenches in spring. On 'organic' soils dung need not exceed 10 or 12 tons per acre.

Celery usually succeeds well on soils which have an acid reaction, and consequently liming is rarely required for the crop, although a soil with an approximately neutral reaction is said to be the best.

When the trenches are being prepared a basal fertilizer mixture should be applied, containing about 70 lb. of phosphoric acid and 70 lb. of potash per acre. Potash may be supplied in any potash manure, but the low grade salts and kainit are often preferred since they also supply common salt, which is occasionally applied separately with the object of increasing the crispness of the stems. Except on fen soils, where nitrogen at planting time is rarely necessary, the basal fertilizer should also supply about 35 lb. of nitrogen per acre, which is generally best given in ammoniacal form. A second application of about 35 lb. per acre should be given as a side-dressing immediately before the second 'earthing-up'. Either nitrate or ammoniacal nitrogen may be used for the side-dressing, but excessive use of nitrogen is considered by some growers to result in soft stems of poor texture. A ton of celery removes about 15 lb. of nitrogen, 5 lb. of phosphoric acid, and 20 lb. of potash.

Lettuce.

1. *Outdoor Cultivation.* For the early market the crop will be transplanted but the main summer crops are grown from seed drilled in the field. In field cultivation the soil organic matter is of great importance, since satisfactory crops can only be grown on a soil well supplied with moisture, but which must also be well aerated. Too much moisture and animal manure may be as detrimental as too little, and the question of what is likely to prove best is directly bound up with the weather. Even on soils which can be irrigated, a fairly high content of organic matter should be maintained for lettuce growing and it may take several years to bring many soils to a suitable condition in this respect. Unless the soil is in very good heart and well provided with organic matter, a heavy dressing of 20 to 30 tons of well-rotted dung or other organic material per acre should be ploughed in for the crop preceding lettuce, since the best results are rarely obtained with freshly turned-in organic matter. Only well-rotted materials should be used and the earlier the organic matter is incorporated with the soil the better.

Lettuce is very susceptible to any marked lime deficiency, and the soil should be maintained in an approximately neutral condition by annual applications of 4 to 6 cwt. of hydrated lime per acre or an equivalent amount of some other form of lime. The

hydrate is usually a high grade material, free from impurities, and is preferred by most high-class growers; it is generally applied as a top-dressing at planting out.

Nitrogen must be carefully used for lettuce since a soft foliage is easily produced which quickly suffers during transport and is very susceptible to disease and bruising. Nitrogen may be applied in readily available organic forms or as ammoniacal, and about 50 lb. per acre of the former or about 30 lb. per acre of the latter should be given, well worked into the soil before planting out or sowing in the field. It is occasionally profitable also to side-dress the summer crop with a quick-acting nitrogenous fertilizer and for early spring lettuce a top-dressing of soot is often beneficial, or about 15 to 20 lb. of nitrogen per acre in quick-acting form should be applied as a side-dressing.

Lettuce requires fairly liberal treatment with phosphates and an application of about 75 lb. of phosphoric acid per acre, the bulk of which should be water-soluble, should be worked into the soil together with the nitrogenous fertilizer before planting or sowing. Potash at about 50 lb. per acre should also be applied as either sulphate or muriate and incorporated with the soil before putting in the crop. A generally suitable basal manure for field lettuce should have approximately the following proportions of plant foods:

Nitrogen.	*Phosphoric Acid.*	*Potash.*
1	3	2

The proportion of nitrogen should be increased if this is supplied solely from organic materials like meat and bone meal. All fertilizers should be applied before the plants begin to 'heart', otherwise hearting may be delayed and 'loose' heads developed.

2. *Cultivation under Glass.* Under these conditions the water available to the crop is largely under control and hence the organic content of the soil is of less moment than in outdoor cultivation. Fresh organic matter is in fact more dangerous for lettuce growing under glass than under field conditions since it encourages mildew. The soil in glass-houses and under frames is generally sufficiently rich in organic matter, and in no circumstances is it advisable to add more unless it be in the form of old, well-rotted compost which can be thoroughly mixed and sieved with the top spit of soil. A deep, regular, and very

fine tilth is necessary, since the soil should, as far as possible, provide the necessary moisture for the crop without recourse to overhead watering after planting out. The foregoing remarks do not, of course, apply to fresh organic matter used for a hot-bed, but only to the overlying soil in this method of culture.

Lime is, of course, equally necessary under glass as for open air culture, and it is probably best to apply high grade hydrate of lime as a top-dressing.

It is not generally advisable to apply nitrogen before planting-out for lettuce under glass, but phosphoric acid as recommended for outdoor cultivation should be worked into the top 3 or 4 inches of soil. Potash should be similarly applied unless the lettuce follows tomatoes which have been liberally treated with potash. Nitrogen may occasionally be applied as a top-dressing to established plants, but care must be taken to keep the fertilizer off the plants. Up to 25 lb. of nitrogen per acre may be applied as sulphate of ammonia or as blood meal, &c.

A ton of lettuce contains 15 lb. of nitrogen, 6 lb. of phosphoric acid, and 30 lb. of potash.

Endive.

Endive should receive similar fertilizer treatment to that recommended for outdoor lettuce, though probably phosphoric acid is of less importance.

Onions (*Spring*).

Since this crop usually follows others which have received farmyard manure, &c., there is seldom need to consider further addition of organic matter. Onions prefer a soil which is not short of lime and any deficiency should be corrected before sowing.

A dressing of about 30 lb. of nitrogen and 75 to 100 lb. of potash should be harrowed into the seed-bed a few days before drilling. The nitrogen should be ammoniacal or in one of the readily available organic forms and the potash as either sulphate or muriate. A further 25 lb. of either nitrate or ammoniacal nitrogen per acre should be given as an early spring top-dressing; this may be slightly increased if the crop is left to mature and not pulled green.

For spring sowings, the potash can be reduced by about 25 lb. per acre and the crop top-dressed once or twice with a similar amount of nitrate nitrogen.

Parsley.

Parsley does not require a soil in high condition, and since it is also often interplanted as a catch crop it requires no special application of dung or other organic material. It usually succeeds best on open, sandy soils, but it will grow on a wide range of soils, though any pronounced lack of lime is detrimental.

Unless it follows, or is grown in conjunction with, a crop which has been liberally supplied with phosphates, a phosphatic fertilizer should be given before seeding. Later the parsley should be side-dressed with a quick-acting form of nitrogen at 25 to 30 lb. per acre; this will usually be given after the interplanted crop has been harvested, where parsley is grown under this system.

Mint.

When mint plants are once established they will grow successfully on practically any soil. Light, open soils are probably best, provided they are well supplied with moisture. On land likely to suffer during dry weather, a good dressing of organic matter should be ploughed in before planting, but on soils which have previously been well treated in this respect further vegetable or animal manure is unnecessary. For the best results a soil well supplied with lime is required.

Before planting-out, a mixture supplying about 25 lb. of ammoniacal nitrogen, 30 lb. of soluble phosphoric acid, and 60 lb. of potash per acre should be harrowed into the soil.

During the following spring a dressing of short farmyard manure at 8 to 10 tons per acre should be spread over the ground. After the first or second cutting, depending on the amount of mint taken, a top-dressing of about 30 lb. of a quick-acting form of nitrogen per acre should be applied. After cutting down the stalks in the second autumn, a dressing of about 30 lb. of phosphoric acid and 60 lb. of potash should be lightly harrowed in, especially if roots are to be lifted for forcing. The following spring and summer treatment will be as recommended for the previous year, except that dung is unnecessary.

Mint plantations are generally kept down for three years only. Where mint is to be used for forcing, nitrogen should be used more sparingly, and the crop should not be cut over severely during the preceding summer.

Radishes.

Radishes require a deep, uniform tilth, a soil capable of steadily providing the crop with moisture but also well aerated. The humus content of the soil is therefore important and the best crops are secured from soils well provided with organic matter. It is, however, not generally advisable to incorporate fresh manure, &c., immediately before sowing this crop, but to grow it after another for which a good dressing of manure has been given.

Although to some extent tolerant of soil acidity, the best crops of radishes cannot be secured on lime-deficient soils and it is necessary to ensure there is no great shortage. Unless the soil is known to be satisfactory in this regard, a suitable dressing of hydrated lime or good quality carbonate should be harrowed into the surface soil a week or two before sowing the seed.

For a single crop it is seldom that any fertilizer is required beyond about 30 lb. of nitrogen per acre. This may be given before seeding in ammoniacal form, or, alternatively, may be applied as a top-dressing of nitrate nitrogen when the plants are through Where several successive crops of radishes are to be taken the nitrogen should be supplemented with about 30 lb. of readily available phosphoric acid per acre, applied before sowing, but for a single crop phosphates and potash are usually unnecessary.

GREEN VEGETABLES FOR COOKING

Except for crops of the cabbage family, the vegetables in this section are not raised in seed-beds, but the fertilizer treatment of the latter for the crucifers should be similar to that recommended for raising the seedlings of salad crops.

The question of the respective merits of organic and inorganic sources of plant food is raised in its acutest form in the manuring of these crops. The extent to which it is desirable to use organic fertilizers is largely determined by first, their price and then the nature of the soil and the cultivations which can be carried out

for the different crops. A soil which cannot regularly be deeply and thoroughly worked requires different manurial treatment from that suitable for a soil which can be deeply cultivated as and when necessary.

The beneficial physical effects of farmyard manure, and other vegetable organic materials applied in comparable amounts, cannot be entirely dissociated from the value of the plant foods provided by such materials. The available evidence, however, does show that the plant foods in organic materials are much less effective than equivalent amounts supplied in inorganic fertilizers. The real issue is, therefore, whether it is possible to obtain by other and less costly means the ameliorative physical action of organic matter. This, of course, only implies that if such alternative methods of securing the desired soil conditions are available they can supplement—but not entirely substitute—the addition of organic matter to the soil. There can be little doubt that proper and adequate equipment combined with a thorough understanding and practice of the art of cultivation will largely secure the aeration, moisture supplying capacity, and ability to withstand drought of the soil. The grower in fact has primarily to decide the extent to which each method can be most economically and conveniently adopted upon his own holding, but there is no dire necessity, and rarely much justification under present-day conditions, for the frequent application of the heavy dressings of purchased organic materials so commonly applied for vegetable crops. Still less can the practice of relying entirely upon organic sources of the plant foods be vindicated; not only are they almost invariably more costly but the grower has less control over their effects upon the crop than with inorganic fertilizers, though, on the other hand, the dangers of excessive application are usually less acute, but more lasting, with organic fertilizers. Nevertheless, many of these crops have a relatively long period of growth and when once they are established it is not essential that all the plant foods are in readily available form.

Asparagus.

This crop does best on a deep, free-working, sandy soil containing sufficient body to ensure a plentiful supply of moisture, but whose texture also provides good aeration. On the

majority of soils, in the preparation of asparagus beds the incorporation of a heavy dressing of organic matter will generally be advisable, particularly since the crop occupies the same land for many years. This initial dressing may supply up to 20 tons per acre of well-rotted vegetable matter, which should be ploughed in as deeply as possible.

Where further dressings of decayed organic materials can be given, they should be applied to established plants in late autumn when working and cleaning the beds. At this time up to 12 or 15 tons of dung, &c., per acre can be given, especially in the early years, though, generally, artificial fertilizers alone will maintain plants in high yielding condition provided good cultivation has ensured aeration, easy movement of soil moisture, and a deep root range.

Asparagus thrives best on soils containing plenty of lime and on most soils therefore a dressing of 2 to 3 tons of chalk per acre, or equivalent, should be applied and thoroughly mixed with the soil during the winter preparation before planting. Subsequently a top-dressing of about 1 ton of carbonate of lime per acre should be given every third year during the autumn working of established crops.

Before planting the crowns, a complete manure supplying about 50 lb. of nitrogen, 100 lb. of soluble phosphoric acid, and 100 lb. of potash per acre should be given. In subsequent years, after the cutting season is over, a dressing of about 30 lb. of nitrogen, 60 lb. of soluble phosphoric acid, and 90 lb. of potash should be worked into the soil. These quantities may be increased by about half when the plants are in full bearing. Although some growers apply salt to this crop, others consider that chlorides are harmful and apply all the potash in the form of sulphate. The summer dressing of nitrogen should be applied in ammoniacal form and the above dressings should be given in addition to organic matter where the latter is available. When the crowns are coming into production in spring, one or two dressings of nitrate nitrogen should be given, supplying in all from 50 to 75 lb. of nitrogen per acre. The spring nitrogen dressing will quicken growth and prolong the cutting season, and the complete fertilizer given later in summer will assist the plants in building up the crowns for next season.

Asparagus may also be forced in the field and for this purpose

a heavy surface application of fresh stable manure or other fermenting organic matter is necessary. It should be given in winter after the autumn clearing and cultivation of the beds.

Rhubarb.

Rhubarb flourishes on soils capable of holding plenty of moisture, particularly on deep, free-working land with a heavy subsoil. Although the crop generally receives heavy applications of organic matter in the form of farmyard manure, satisfactory crops may be obtained with fertilizers alone on soils not subject to lack of moisture. In preparing land for planting it is desirable, after deep working, to plough in from 12 to 15 tons of well-decayed organic matter per acre, except on soils containing an abundance of humus. In subsequent years organic manure is not essential, except for surface application where the heat from fermenting materials and protection from weather encourages earlier production of stalks. Where plenty of organic manure is available, however, a dressing of 10 to 12 tons per acre may be given during the second spring after cleaning the crop, and is indeed advisable on open textured soils. Where sewage effluent is obtainable it may be used on rhubarb with satisfactory results.

Although rhubarb can succeed under very acid soil conditions, they are not conducive to the best results and on soils with an acid reaction an application of 1 to 2 tons of quicklime or its equivalent per acre should be worked into the surface soil after preparing the land for planting.

Few crops will respond better than rhubarb to heavy fertilizer dressings. During the early spring cultivation and cleaning, a complete fertilizer should be applied supplying about 75 lb. of nitrogen, 75 lb. of phosphoric acid, and 150 lb. of potash per acre. The nitrogen in this basal dressing should be in ammoniacal form, part at least of the phosphate readily available, but the potash may be supplied from any of the potash fertilizers. After each heavy pulling, a dressing of 50 to 75 lb. of nitrogen per acre should be given either as ammoniacal or nitrate, or a mixture of the two. Abundant readily available nitrogen is necessary for rapid growth and crisp stalks, and some growers apply from 300 to 400 lb. of nitrogen per acre during the season on heavy-yielding beds. After the final pulling,

a dressing of 50 to 75 lb. of nitrogen per acre is desirable to build up the crowns for the next season.

Summer dressings, especially late in the season, should not be applied to roots intended for forcing, since nitrogen delays ripening, and it is essential that the crowns mature early and thoroughly before they are lifted for forcing.

A ton of rhubarb stalks removes 8 lb. of nitrogen, 2 lb. of phosphoric acid, and 20 lb. of potash.

Seakale.

This crop succeeds best on deep, well-drained soils of light open texture, and it benefits from the residues of organic matter applied to the previous crop, but it is not usually considered necessary to dress with farmyard manure, &c., for seakale.

It is susceptible to any serious shortage of lime and the requirements of the soil in this regard should be met, where necessary, by an application before planting the 'thongs'. During the final working in spring a dressing of about 30 lb. of nitrogen, 60 lb. of soluble phosphoric acid, and a similar amount of potash per acre should be harrowed into the soil. When the shoots appear above the surface a side-dressing of about 30 lb. of nitrogen per acre should be hoed in. This nitrogenous dressing is often given together with 1 to 2 cwt. of common salt per acre where potash is not given as kainit or low grade salts.

During subsequent years, spring dressings of nitrogen at the above rates should be given before earthing-up and further top-dressings of quick acting nitrogenous fertilizers can be given at approximately monthly intervals. If the plants are to be lifted for forcing, the use of nitrogenous fertilizers must be discontinued early in summer, in order to ensure well ripened roots at lifting. In dry districts the beds may be given a light dressing of organic material in spring after applying the first nitrogenous dressing. The organic material acts as a surface mulch and reduces the loss of soil moisture. The plants may also be slightly forced in the field by plentifully covering the crowns with fermenting organic material.

Beans (Broad).

Beans require a good bodied and well-drained soil for the best results, but they will thrive on a wide variety of soils.

Although beans respond to farmyard manure it is rarely desirable to apply organic materials for this crop, since better use can be made of them for other vegetables, and they tend to encourage an excessive growth of haulm.

It is important to ensure that the soil is not deficient in lime, and any tendency in this direction should be corrected by harrowing-in a dressing during the preparation of the seed-bed.

During the final working of the soil before seeding, a dressing should be given of about 45 lb. of soluble phosphoric acid and 60 lb. of potash per acre. On heavy soils the potash should be given in one of the high grade manures and on these soils basic slag is a very suitable phosphatic fertilizer.

A ton of beans in pod contains 22 lb. of nitrogen, 6 lb. of phosphoric acid, and 20 lb. of potash, and the amounts in a ton of dry haulm are about 24 lb. of nitrogen, $8\frac{1}{2}$ lb. of phosphoric acid, and 27 lb. of potash.

French or Haricot Beans.

For this variety of bean a lighter and freer working soil is desirable and, unless the land is well provided with humus, a dressing of 12 to 18 tons of well-rotted organic matter per acre should be ploughed in before preparing the seed-bed.

If the soil is at all acid, a dressing of lime must be worked into the surface soil after ploughing, since haricot beans require a soil well provided with lime.

Before seeding, an application of about 75 lb. of soluble phosphoric acid and from 75 to 100 lb. of potash per acre should be made, the potash being preferably in the form of sulphate. On soils in good condition the crop does not always respond to nitrogen and consequently this is best supplied as a side-dressing and hoed in where the plants are checked in the early stages of growth, or during dry weather. About 25 lb. of nitrogen per acre is a suitable dressing and where slugs are troublesome the nitrogen may well be supplied in soot. On soils not in good condition the nitrogen may be applied with the other fertilizers before drilling the seed.

Runner Beans.

These prefer a deep sandy soil, well supplied with moisture, and should receive up to 25 tons of well-rotted organic matter

per acre, ploughed in deeply in autumn. Liming is equally as necessary as for the other varieties, and phosphates and potash should be given as for haricot beans. Nitrogen may be used more freely on runners and should be applied as a side-dressing if the young plants are not developing satisfactorily. Generally, however, where the soil is in good heart from organic residues, nitrogenous fertilizers are not required for the bean family.

Peas.

Peas require a well-drained soil, not subject to early droughts, but without a large amount of organic matter as this encourages an excessive growth of soft haulm. Organic manure should not, as a rule, be given and, except on light soils, the best results are unlikely to be obtained if peas follow a heavily dunged crop.

Peas only thrive on soils well provided with lime, and where there is any tendency to lime deficiency a suitable dressing should be harrowed in after the final ploughing.

The fertilizers applied in the seed-bed should supply about 60 lb. of soluble phosphoric acid per acre and a similar amount of potash. Nitrogenous fertilizers are only likely to be required in the seed-bed for early spring sowings on light open land, for which about 20 lb. per acre may be given. Under other circumstances where development is normal a side-dressing of nitrate nitrogen at the rate of about 25 lb. per acre should be applied as near to flowering time as possible. This top-dressing not only encourages the pods to fill more quickly but also tends to improve the colour. Nitrogen must be used cautiously before the pods begin to form since in the earlier stages of growth it encourages leaf and haulm and tends to delay flowering.

A ton of peas in pod removes about 30 lb. of nitrogen, 8 lb. of phosphoric acid, and 12 lb. of potash. A ton of dry haulm contains 31 lb. of nitrogen, 9 lb. of phosphoric acid, and 22 lb. of potash.

Cabbage.

Although cabbages respond to farmyard manure it is not necessary on most soils and need only be considered on the lighter soils or where the crop follows one for which organic matter has not been given. Under the latter conditions, a dressing of about 15 tons of well-rotted material per acre may be ploughed

in before planting, except for drilled spring cabbage which demands a very firm seed-bed.

Any lime deficiency should be corrected before planting or sowing the crop, although on land not subject to 'Finger and Toe' a slight acidity is not important.

A fertilizer supplying about 75 lb. of phosphoric acid per acre should be harrowed into the seed-bed and part may be in insoluble form. The organic sources of phosphoric acid appear to be particularly suitable to the cabbage family; some of the phosphates can be given in bone manures, &c., provided some quickly available phosphoric acid is also supplied upon which the plant can draw in the early stages of growth. Cabbages require abundance of readily available plant foods at the time of planting-out at which stage there is a large intake of nutrients.

Potash is probably best given as low grade salts supplying about 75 lb. of potash per acre and should be applied together with the phosphates. For summer cabbage, especially on good land, the potash can be reduced to about 50 lb. per acre.

For summer cabbage, a dressing of 35 lb. of nitrogen per acre should be given shortly after planting-out, and on varieties to be cleared in autumn a second side-dressing about the same rate should be hoed in when the plants are beginning to heart. On winter sorts and savoys, however, the second dressing is inadvisable if the plants have developed satisfactorily, since quickly grown plants are more susceptible to frost damage and 'splitting' and this cautious use of nitrogen applies particularly to savoys.

Spring cabbage should require little nitrogen during the year of sowing, except on poor land where about 25 lb. per acre of ammonia nitrogen may be given along with the other fertilizers in the seed-bed, or prior to planting-out. Subsequent fertilizer treatment should be withheld until the following spring and will usually commence during the latter half of February. A side-dressing of a nitrogenous fertilizer supplying about 25 lb. of nitrogen per acre should then be given and for spring greens should be succeeded by three or four similar dressings at 10- to 14-day intervals. On light soils where potash has not been given as kainit, the spring nitrogen dressings are probably best supplied as nitrate of soda or nitrate of potash, otherwise ammonia nitrogen is equally suitable. If the crop is to be sold

as 'greens' nitrate of lime may also be used but the nitrates tend to delay hearting. It is important to keep the nitrogenous fertilizer off the foliage since at this time of year there is danger of scorching and spotting the leaves. For all row-crops it is important to remember that side-dressing is always preferable to a broadcast top-dressing.

Where the crop is to be left to heart, two top-dressings of nitrogen in spring should suffice, and for this purpose the nitrogen is probably best given in ammoniacal form. Potash is more important where the crop is left to heart than for spring greens.

A ton of cabbage contains approximately 8 lb. of nitrogen, 2 lb. of phosphoric acid, and 7 lb. of potash.

Brussels Sprouts.

A deep, friable soil with good moisture holding capacity is required for sprouts and since the crop is also a heavy feeder it commonly receives very heavy dressings of farmyard manure —up to 25 tons per acre. It is very doubtful if such heavy dressings of organic matter are profitable, especially as the crop often follows one which has been liberally treated in this respect. The latter method is usually considered better than applying large amounts of organic matter direct to sprouts, but where organic material has not recently been given a dressing of 10 to 15 tons of well-rotted dung should be ploughed in early on light soils. An open soil at planting is most undesirable so that organic materials should neither be fresh nor be worked in just previous to planting-out.

Sprouts are susceptible to lime deficiency in the soil and any acidity should be corrected by a suitable dressing harrowed into the surface soil during the spring cultivations.

A complete basal manure should be applied before planting and should provide about 30 lb. of nitrogen, 60 to 90 lb. of phosphoric acid, and 60 to 90 lb. of potash per acre. The nitrogen should be in ammoniacal or organic form, and if the latter, the above amount may be doubled or trebled. The phosphoric acid may be partly soluble and partly insoluble, organic sources of the latter being favoured by many growers. The potash may be supplied in any form and on all but heavy soils the low grade salts are very suitable.

During July a side-dressing of 30 lb. of nitrate nitrogen

per acre should be hoed in, and should be followed by a similar dressing three or four weeks later. If heavy dressings of organic nitrogen have been given before planting it is usually desirable to reduce the nitrogenous side-dressings, or even omit the second entirely, since an excess of nitrogen tends to produce 'blowers', i.e. loose, open sprouts instead of tightly folded ones, more especially if there is any lack of potash.

Kale.

This crop should be manured in the same way as sprouts.

Cauliflower.

The soil must be in good condition and capable of carrying the crop without any serious check, if satisfactory heads are to be secured. Organic matter is of considerable value in producing the desired conditions but it is preferable to depend upon a heavy dressing for the previous crop rather than direct application for cauliflowers. Where this cannot be arranged, very well-rotted farmyard manure at about 12 to 15 tons per acre should be ploughed in as early as possible or alternatively 2 to 3 tons of shoddy or other comparable material may be given and well buried.

Like all the crops of the cabbage family, the cauliflower suffers from deficiency of lime and any acidity should be corrected by working a suitable dressing into the soil before planting out.

A complete fertilizer dressing should be harrowed in before planting-out and should supply about 50 lb. of nitrogen, 50 lb. of phosphoric acid, and 75 lb. of potash per acre. Many growers prefer to apply most of the initial nitrogen in organic form and in such cases three-quarters may be given in hoof and horn or meat and bone meal, &c., the balance being made up with an ammoniacal fertilizer; some quickly available nitrogen should be provided for the young plants. The phosphate should be in one of the readily available forms and the potash is usually applied as the sulphate or chloride.

One or two side-dressings of nitrate nitrogen supplying about 25 lb. of nitrogen per acre should be hoed in about the time the plants are beginning to 'turn in'.

One ton of cauliflowers removes about 8 lb. of nitrogen, 1½ lb. of phosphoric acid, and 4 lb. of potash.

Broccoli.

For winter cauliflowers a soil in very high condition and rich in nitrogen is not desirable and farmyard manure or other organic material should not be required except possibly on light, sandy soils to which a dressing of about 10 to 15 tons of well-rotted dung or vegetable compost per acre may be given and deeply ploughed in before planting.

Lime should be applied if there is any suspicion of soil acidity, since winter leaf-drop is most prevalent on lime deficient soils.

Phosphates should be given as recommended for cauliflowers, but nitrogen must be used on a more moderate basis before winter. A side-dressing of quickly available nitrogen at about 25 lb. per acre should be given if the plants experience any check after planting-out before they are well established. When the heads are beginning to heart about 25 lb. per acre of ammonia or nitrate nitrogen should be applied as a side-dressing which may be repeated on late spring sorts. Potash should be used more freely than on summer cauliflowers and about 100 lb. per acre as sulphate is suitable. Potash deficiency leads to more leaf damage by frost and to open and yellow or stained curds.

Spinach.

This crop is grown practically all the year round since some varieties are resistant to all but severe frosts. For the spring and summer crop, organic matter is important since spinach must have a good supply of moisture and unless the soil is already well provided a moderate dressing of 12 to 15 tons of well-rotted manure or compost should be ploughed in before sowing. This provision is not so important for the winter crop, since during this season there is small likelihood of lack of moisture curtailing growth; on soils in poor condition, however, a moderate dressing of farmyard manure is advantageous for the winter crop, but fresh manure is always inadvisable.

Spinach succeeds best on soils well provided with lime, and any indication of acidity should be corrected by harrowing in a suitable dressing of hydrate or carbonate during the preparation of the seed-bed.

For both winter and summer crops from 50 to 75 lb. of soluble phosphoric acid per acre should be applied to the seed-bed.

About 50 lb. of potash per acre should be given, except to the summer crop which has received farmyard manure, in which case potash may be omitted. On very light soils for winter spinach the potash may be increased to about 75 lb. per acre.

Spinach responds to heavy dressings of nitrogen and the first application should be given at singling and provide 30 lb. per acre in a quick acting form. Three weeks later a second side-dressing of a similar quantity of nitrate nitrogen should be applied, and a third side-dressing of nitrogen may be given to the summer crop where growth is slow or where it is desired to prolong picking.

For the winter crop the application at singling time should be rather smaller than for the summer crop, and the subsequent side-dressings deferred until early spring, when two or three applications of about 25 lb. per acre should be given at approximately fortnightly intervals.

A ton of spinach removes about 10 lb. of nitrogen, 4 lb. of phosphoric acid, and 20 lb. of potash.

Leeks.

The leek can be successfully grown on a wide variety of soils, but responds to generous treatment, particularly with farmyard manure. It is preferable to apply the latter to the preceding crop, but where this course has not been possible, up to 25 tons of well-rotted organic material per acre should be deeply ploughed in as early as possible.

A complete basal mixture should be harrowed in before planting-out or sowing in the field. This mixture should supply about 45 lb. of ammonia nitrogen, 45 lb. of soluble phosphoric acid, and 90 lb. of potash per acre. A further 50 lb. of nitrogen in quickly available form should be applied as side-dressings and hoed in before earthing up.

Vegetable Marrow.

This crop requires very generous manuring, but will succeed on almost any soil which is well supplied with moisture. The soil should therefore contain a high proportion of organic matter, unless the crop can be regularly watered. If the soil is not already rich in humus, a heavy dressing of well-rotted organic

material, up to 25 tons per acre, should be deeply ploughed in. Some growers prefer to plant in 'hills' which are made on top of a small pile of dung or compost.

Marrows are not very susceptible to soil acidity and will thrive on soils where lime deficiency may reduce the yield of many other vegetable crops.

During the final cultivations prior to planting-out, a complete fertilizer should be deeply worked into the soil. The mixture should supply about 50 lb. each of nitrogen, phosphoric acid, and potash per acre. Half of the nitrogen may be given in ammoniacal form or in soot where slugs are troublesome, and the remainder in one of the organic manures such as hoof and horn meal. At least part of the phosphoric acid should be in soluble form.

When the fruits are beginning to set, a side-dressing of 30 to 40 lb. of a quick-acting nitrogenous fertilizer per acre may be applied by hand round the plants.

ROOT VEGETABLES

Artichokes (Jerusalem).

This crop flourishes in dry situations and consequently the supply of organic matter in the soil is of little importance. Nevertheless artichokes respond to good conditions and if the soil has not recently received vegetable material, an application of about 10 tons of well-rotted compost or manure is desirable though not essential. It should be ploughed in during winter or early spring.

A complete fertilizer supplying about 45 lb. of nitrogen, 45 lb. of soluble phosphoric acid, and 60 to 80 lb. of potash as sulphate, should be harrowed in shortly before making the drills for planting.

Beetroot.

Beetroot requires a soil in moderately good condition but not too rich, and it is usually undesirable to apply organic material direct for the crop. If possible beet should succeed a crop which has been fairly liberally dressed with vegetable or animal manure. On very light soils containing little organic

matter, about 10 to 12 tons of well-rotted farmyard manure can be given, but it should be ploughed in during autumn or early winter.

Beet cannot be grown successfully on sour soils since it is a crop particularly susceptible to any appreciable lime deficiency. Under nearly all circumstances it is advisable to work a dressing of lime into the surface soil during the spring cultivations.

A complete fertilizer should be harrowed into the seed-bed before sowing, and should contain about 25 lb. of nitrogen, 50 lb. of soluble phosphoric acid, and 75 to 100 lb. of potash either as muriate or sulphate per acre—the heavier rate on very light soils.

After singling, a further application of about 25 lb. of quick-acting nitrogen per acre should be given as a side-dressing in most cases. There is some danger from an excess of nitrogen to the round, summer beet since it may encourage a lighter coloured centre in the bulb. There is much less danger with the long varieties which can be more generously fertilized.

Carrots (Bunching).

Bunching carrots require a soil in first-class condition with a deep fine mould, and should, if possible, follow a crop for which a liberal dressing of organic manure has been applied. Direct application of undecayed organic matter is inadvisable for bunching carrots.

Carrots are not particularly susceptible to slight soil acidity but, since they are usually grown on open soils which tend to lose lime quickly, if there is any pronounced lime shortage it should be corrected by harrowing in a dressing before seeding.

A complete fertilizer dressing should be worked into the seed-bed a few days before sowing and should supply about 20 lb. of nitrogen, 60 lb. of soluble phosphoric acid, and 60 lb. of potash per acre. Some growers apply up to 1 ton of soot per acre and in such circumstances no further nitrogen should be applied in the seed-bed.

Immediately after thinning, a top-dressing of a quick acting nitrogen fertilizer should be given at a rate supplying about 25 lb. of nitrogen per acre. A second similar dressing should be given about a fortnight later, especially if the crop is not developing rapidly.

Less nitrogen should be used on bunching carrots grown for canning, since under some conditions it may encourage light-coloured centres. Consequently, at least on soils in good condition, the second nitrogenous top-dressing should be omitted and the first may be reduced if the crop is growing satisfactorily.

Onions (*Maincrop*).

This crop usually thrives best on free working sandy loams, and although it responds to heavy dressings of farmyard manure, satisfactory crops can be grown without the addition of organic material, particularly where onions follow a crop which was liberally treated in this respect. A steady supply of moisture during the development of the bulb is desirable since a serious check leads to mis-shapen and split bulbs. On land subject to the effects of mid-summer droughts the amount of organic matter in the soil is therefore important. On light soils, a green-manure crop may precede onions or a dressing of about 15 tons of well-rotted manure should be ploughed in early, in order to allow the land to settle and give a firm seed-bed. Excess of organic manure, especially if fresh, encourages coarse onions and may unduly delay ripening.

Onions prefer a soil well supplied with lime but a slight degree of acidity does not appear to be important. Nevertheless good onion soils usually contain adequate reserves of lime and any serious deficiency should be corrected by working in a dressing after ploughing.

Fertilizers supplying about 25 to 50 lb. of nitrogen, 50 lb. of soluble phosphoric acid, and 75 to 100 lb. of potash per acre should be harrowed in shortly before seeding. The nitrogen should be in readily available form, the smaller application being used after farmyard manure, and the higher rate of potash should be used on light types of soil or where no farmyard manure has been applied for the crop. Potash is considered to improve the keeping quality of onions and lack of this food results in delayed ripening and may induce malformation of the bulbs.

Following the first weeding and thinning, a side-dressing of 25 lb. of nitrogen per acre should be given and is often applied in soot. A second similar side-dressing can be given about one month after the first, but this is not usually necessary on land

in good condition, where in fact it may appreciably delay 'ripening off'.

Where onions are grown for pickling they are usually treated less generously since smaller and harder bulbs are required.

Turnips (Culinary).

Turnips are usually grown as a catch crop and although on light soils farmyard manure is valuable, there is seldom need to apply organic material for this crop. It must be grown quickly to prevent the flesh becoming woody, and readily available plant food and no lack of moisture are essential.

It is very susceptible to any shortage of lime and unless the soil is known to be satisfactory in this respect and free from disease, a good dressing should be harrowed in immediately after ploughing.

The fertilizers applied to the seed-bed should supply 25 lb. of nitrogen, 50 lb. of phosphoric acid in water-soluble form, and 25 lb. of potash, though on light land and for the winter crop the potash may be increased to 50 lb. per acre. After the plants are established they should be top-dressed with 25 lb. of nitrogen per acre every two or three weeks.

FRUIT

It is more difficult to give recommendations for the manuring of fruit than for other crops since so many special considerations are involved which do not arise to nearly the same degree under other types of cultivation. Fruit trees and bushes are not annual plants but occupy the same land for many years, so that the bad effects of wrong treatment in one season may be experienced for several ensuing years. Moreover, a high yield per acre may be secondary to the quality of the crop, which involves the appearance, colour, flavour, carrying, and keeping qualities of the fruit, all of which are influenced by cultural treatment. The type of soil has naturally an important bearing upon manuring and since good drainage and ability to retain sufficient moisture for the crops' requirements during the fruiting season are most essential, the maintenance of a suitable proportion of organic matter in the soil is a vital consideration for shallow rooting types and in the early years of development

of the plants. Moreover, trees need different treatment during the growing or formative period from that they should receive when they have reached the full bearing stage. Further complications are introduced by the different types of stocks for top-fruits, as well as by the differing requirements of the varieties themselves, and the fact that with some kinds of fruit it is usually necessary to have two or three varieties in a plantation to ensure satisfactory pollination. Trees under arable cultivation generally require radically different fertilizer treatment from those grown under grass. Such features as alternate bearing and susceptibility to fungoid diseases are probably influenced by manuring, and as the latter affects growth, the manuring may to some extent increase or decrease the amount of pruning required. It is therefore no exaggeration to say that the manuring of fruit demands more skill, judgement, and close observation than any of the crops which have been previously considered.

Before passing to a more detailed review of the manurial treatment for various kinds of fruit, some of the general effects of different plant foods may be outlined.

Nitrogen largely governs the growth of wood and leaf, it stimulates a greater general activity of the plant, inducing large, dark green foliage and large, well-developed fruit. An excess of nitrogen is indicated by rapid vegetative growth, leaf-scorch symptoms where potash is deficient, soft long-jointed wood which may not harden off satisfactorily before winter, greater susceptibility to fungoid diseases, and in some species, lack of full colour development in the fruit. Apples on trees grown with too much nitrogen may have soft flesh and are likely to have poor keeping qualities. Lack of nitrogen is exhibited by the converse of many of the foregoing characters, i.e. slow growth, delayed opening of blossoms and leaves, small buds, thin shoots, yellowish foliage with small leaves which fall early and are highly coloured. Fruits are small, often highly coloured, but yields are meagre, and on nitrogen starved apple trees the summer 'drop' is usually much more severe than where the nitrogen supply is satisfactory.

Phosphoric acid, though probably of less importance for fruit than the other fertilizer ingredients, has effects which may be distinctly correlated with certain habits of growth. Phosphoric acid deficiency is typified by late and rather weak

blossoming, fruit buds are small, and the foliage develops a purple bronze colour as the season advances, and falls prematurely. Sufficiency of phosphoric acid promotes strong blossoming, encourages young, strong growing trees to come into bearing, and to some extent acts as a corrective to an excess of nitrogen. Under practical conditions, however, fruit rarely suffers from deficiency of phosphoric acid, but some growers consider that earlier ripening of fruit is obtained by the use of phosphates.

Potash fertilizers are particularly important for fruit. Potash deficiency is demonstrated by marginal leaf-scorch in conjunction with premature drop of leaves, which often first fall from the tips of the shoots. Potash encourages the ripening of wood, hardens new growth, and tends to counterbalance in many ways the effects of excessive nitrogen. Potash deficient foliage is often small and dark in colour early in the season, later develops marginal scorch, and in some varieties is more susceptible to damage by spray fluids. Opening of leaf and blossom buds may be accelerated, shoot growth restricted, fruit may be plentiful but dull in colour and small. Although the application of potash on soils lacking this plant food usually improves the colour and quality of dessert apples, the correction of severe potash starvation may stimulate wood and foliage development to such an extent that fruit colour may suffer for some time.

Lime deficiency is rare on top fruit, but under experimental conditions is indicated by leaf-scorch—in this instance along the veins rather than the margins. Lime also promotes hardening of the wood and has been shown to improve the general tone of the plants grown under conditions of marked lime deficiency. Stone fruits have more ample needs for lime than other top fruits, and pears are probably more tolerant of lime deficiency than apples. Lime, however, is similar to phosphoric acid in that established fruit trees, especially the larger varieties, rarely show a response to applications of these two nutrients.

Apples.

For established trees which have begun to bear it is not necessary to supply organic matter since the roots will obtain moisture from the deeper layers of soil, of which the moisture holding capacity will not be greatly affected by additions of

organic material to the surface soil. When planting an orchard it is important to protect the young trees from the effects of drought, and unless the previous treatment of the land has included deep and thorough cultivation and provided a good supply of humus, it is advisable to give organic matter. This is especially needful on the lighter types of soil. The crop previous to planting should be one that leaves the soil in deep, friable tilth with a good residue of humic materials. Where such preparation cannot be made, organic matter should, if possible, be provided by a dressing of well-rotted dung or by ploughing-in a green-manure crop during the year of planting. On soils of very open texture, further additions of organic materials for young trees are desirable where circumstances permit of their economical provision.

Established trees seldom show symptoms of lime deficiency, perhaps because the roots explore a great depth of soil, and surface soil acidity is of little consequence. Before planting young trees, especially for dwarfing stocks, it is possible that correction of pronounced soil acidity may be all to the good, but there is little evidence to suggest that, even under these conditions, apples suffer from soil lime deficiency.

When preparing land for planting, phosphates and potash should be deeply worked into the soil and where possible the preceding crop should be liberally treated with these plant foods. From 50 lb. of phosphoric acid per acre on light soils, up to 100 lb. per acre on heavy land and on soils containing much organic matter, should be worked in when preparing the land for planting. On light soils, chalks, and 'organic' soils, about 100 lb. of potash in sulphate form per acre should also be worked in before planting.

During the first three or four years the growth of the trees should be carefully watched for indications of the type of fertilizer treatment required. It is patent that no general rules for the use of fertilizers can be laid down when so many factors influence the nutrition of the trees, and fertilizers must be used according to their effect when combined with those of weather, stock, variety, cultivations, pruning, age of tree, and type of soil. The needs of the trees must be recognized by careful and continuous observation and the plant foods applied accordingly in the light of their effects, as previously indicated. Among the

many factors affecting the yield and quality of apples, some, such as sunshine, temperature, and rainfall, are outside the control of the grower, but he can adapt his manuring and cultural practices to modify the effects of these natural agents. Factors which in a general way tend to lessen the need for nitrogen include, plentiful moisture, clean cultivation, vigorous varieties and stocks, young and strong growing trees, and hard pruning. The converse of the foregoing indicate that nitrogen can be used more freely, e.g. in districts or periods of light rainfall, on dry soils of open texture, on apples grown under grass, and for mature or weak growing trees. Thus by judicious regulation of the amount of nitrogen applied and of the frequency and extent of cultivations during the growing season in relation to the weather and the condition of the trees, the grower is able to exert a large measure of control over the yield and quality of the fruit. In view of the importance of regulating the nitrogen uptake of the trees it will be appreciated that it is generally better to rely upon inorganic nitrogen than upon slow acting organic nitrogenous manures from which the nitrogen is liberated slowly and over long periods.

Young trees generally respond to a spring dressing of about 25 lb. of nitrogen per acre in either ammonical or nitrate form. If, however, they are grown in circumstances where good growth may be reasonably expected, and if weather conditions are also favourable, the spring nitrogen dressing in the first three or four years may be unnecessary.

At about five or six years old the manuring will be based upon the requirements for fruiting, since the trees will be coming into bearing. Naturally, for standards, this stage may be postponed a year or two, and on some bush varieties it may be reached at four years under conditions conducive to early bearing.

It is generally found in this country that potash is equally as important as nitrogen for apples under arable cultivation. So long as no symptoms of potash deficiency are seen, the trees should receive an annual application of about 100 lb. of potash per acre in one of the high grade potash manures, sulphate of potash being preferable. For free-growing stocks on heavy soils this dressing may be reduced, or applied less frequently as the trees mature. If the trees indicate the need for more potash, and marginal leaf-scorch is usually the first sign to be noted, the potash

dressing should be increased to 200 lb. or 300 lb. per acre and this amount should be applied annually until deficiency symptoms disappear. Ordinarily the potash manure should be applied in autumn or early winter. Low grade potash manures are not generally suitable for fruit, and for young trees and on light soils potash should always be applied as sulphate.

To regular cropping trees, those which are not making excessive wood growth, and on varieties which are not readily affected by nitrogen, a dressing of about 25 to 50 lb. of either nitrate or ammoniacal nitrogen per acre should be worked into the soil during February or March. Nitrogen should be withheld from trees which are short of potash and must be used with most circumspection on highly coloured dessert varieties, particularly Worcester Pearmain. Nitrogen should be applied in early spring to obtain its effect on blossom development, and to minimize the effects of late spring drought. Where a heavy crop is expected, a second dressing of quickly available nitrogen at 25 lb. per acre should be given in early June, unless other factors make this second dressing inadvisable. The post-blossom dressing of nitrogen has a wider application amongst cooking than dessert apples and especially for the late culinary varieties.

The foregoing recommendations are intended to provide a basis for the manuring of cultivated orchards, but under grass similar treatment is required except for more liberal use of nitrogen. The bulk of the nitrogen applied to permanent grassland does not become available to the trees, consequently applications at about double the rate customary in cultivated orchards are required. Moreover, where possible, the grass should be kept closely grazed, and where this cannot be achieved the herbage should be cut down two or three times during the season, before the grass has become woody. It is desirable to encourage a close leguminous sward, and to this end the herbage must be kept closely eaten, particularly in spring and late summer, and every second or third year should receive a dressing of about 60 lb. of readily available phosphoric acid per acre.

Sowing the land down to grass is one means of counteracting excessive wood growth and the general effects of too much nitrogen. The turf also to some extent regulates the moisture additions to the soil: heavy summer rains are partially absorbed

by the turf and do not pass so rapidly into the soil as in cultivated orchards. In consequence there is usually less danger from 'bitter pit' and storage breakdown from apples grown under grass. Where treatment less drastic than grassing down is expected to suffice, the grasses and weeds may be allowed to grow during the summer, and cultivations restricted to winter. Conversely, in a grass orchard where tree growth is backward and nitrogen deficiency indicated, the orchard may be brought into arable cultivation for two or three years. This will generally be found more satisfactory in severe cases than very heavy dressings of nitrogen.

Fertilizers influence the quality of the fruit for storage purposes but naturally their effects are merged with those of all the other factors affecting storage capabilities. Apples of the best keeping character are not generally produced under what may be termed vigorous growth conditions, i.e. from young trees, high nitrogen supply, and very plentiful moisture. The effects of fertilizers on storage quality cannot readily be segregated from the large complex of factors influencing this character, and the ordinary use of fertilizers is unlikely to have a predominant effect on the keeping quality of the fruit.

Pears.

Although there is little information on the manuring of pears which is established by experiment, the general experience of commercial growers indicates that the manurial treatment should be very similar to that for apples but more generous.

During the first few years after planting and after the trees come into bearing, they may be treated on the lines recommended for apples, except that pears probably do not show quite the same need for potash and can be more liberally treated with nitrogen. Varieties on quince stocks usually require more liberal fertilizer treatment than on free stocks, but generally speaking the pear seems to be more accommodating in its requirements than the apple.

Cherries.

Cherries are most commonly grown on good medium loams overlying a chalk subsoil and, as for other stone fruits, a liberal amount of lime in the soil appears to be desirable.

If the surface soil is markedly deficient in lime it is probable that liming would improve conditions for the planting of young trees. In regard to other plant foods, the manuring should approximate to that recommended for apples during the first few years of the plantation.

The regular supply of moisture during the fruiting season is all important and, probably for this reason, cherries are usually grown under grass and it is desirable that the herbage be kept short and leguminous. With this object, about 50 lb. of soluble phosphoric acid per acre should be applied about every other year. This may be conveniently given in autumn in the form of high-soluble basic slag or as a spring dressing of superphosphate. In addition, from 50 to 100 lb. of potash per acre in one of the high grade potash manures should also be applied. On highly calcareous soils the higher rate of potash application is desirable and this dressing may be applied in conjunction with the phosphates every alternate year.

The stone fruits should be more liberally treated with nitrogen than is usually desirable for apples, and for cherries under grass from 50 to 100 lb. of readily available nitrogen per acre, according to the condition of the trees, should be applied in early spring in grass orchards. Where cherries are grown in cultivated soil probably half this amount of nitrogen will suffice.

Plums.

The plum is one of the hardiest types of fruit and succeeds on a wide variety of soils, but requires good drainage and usually thrives best in soils well supplied with lime. Soil acidity therefore, where present, should be corrected by an adequate dressing of lime at or before planting, and subsequent applications of about half a ton per acre given every second or third year, except of course on chalk sub-soils.

The manurial treatment during the early years after planting should be similar to that recommended for apples, but plums require larger quantities of nitrogen, and dung may therefore be given much more liberally than is generally advisable for apples. Plums are the most suitable kind of fruit for intercropping with market-garden crops, and where this practice is followed during the early life of the trees they are unlikely to

need special manurial treatment, provided the vegetables are adequately manured.

When the trees come into bearing they require relatively large amounts of nitrogen. This may be given in either dung or fertilizers. On large trees up to 15 tons of dung per acre may be applied annually in late winter or early spring, where supplies are available. In conjunction with the animal manure a dressing of 50 to 100 lb. of potash per acre should be applied in autumn or early winter.

In years when farmyard manure on the foregoing basis is not given it will be necessary to apply from 50 to 100 lb. of nitrogen per acre, according to the size and condition of the trees. Up to 50 lb. of the nitrogen per acre in a readily available form should be harrowed in during February or March and 100 lb. of potash should be applied in autumn. The balance of the nitrogen should be given about petal fall. Under some conditions, most probably on light soils which have been heavily dunged, it may be that the potash dressings will need to be increased up to 150 to 200 lb. per acre, and similarly with nitrogen for trees under grass which have not received animal manure.

Bush Fruits.

Many of the earlier general remarks upon the manuring of fruit apply to bush fruits, but since many of these are for the most part relatively shallow rooting, certain aspects of manuring are particularly important. The bush fruits, to a larger extent than tree fruits, depend on the upper soil for moisture and nutrient materials, and moreover the fruit is developed in a comparatively short period, during which an abundant supply of moisture and food materials must be available to obtain anything like full crops. It need not be emphasized that although plenty of moisture is necessary it must not be present as stagnant water, but must be well regulated throughout the year. The soil must be well-drained during winter, while retentive of moisture in late spring and summer, hence the importance of maintaining a large amount of organic matter in soils planted with bush fruit and the equal necessity of frequent shallow working to preserve a surface mulch to reduce evaporation during summer. Surface cultivation therefore should be

continued at least until fruiting is over, so long as operations can be carried out without damage to the plants.

Bush fruits are manured on a heavier scale than tree fruits since liberal fertilizer dressings, to provide easily available plant foods, must be combined with the free use of organic materials to secure a moisture retentive root range. Generally speaking, where farmyard manure is available an annual dressing can be given to all bush fruit, and where dung must perforce be more sparingly used other means must be found of building up the organic reserves of the soil. Consequently it is for the manuring of bush fruit that the various waste vegetable materials are of greatest value, and needless to add, the cropping before planting bush fruit should be designed to leave the soil well provided with organic matter.

Gooseberry.

Although gooseberries require a soil well provided with moisture during late spring and early summer, this should not be secured by the selection of a low lying, damp site, where free air circulation is impeded. An open, unshaded, and well-drained situation is desirable to avoid trouble from American mildew.

A heavy dressing of organic material should be incorporated with the soil during the cultivation prior to planting. Where farmyard manure can be spared, up to 20 tons per acre should be given unless the preceding crop has been liberally treated in this respect, when a more moderate dressing will suffice. Where a satisfactory dressing of dung cannot be given, a green crop should be ploughed in or some other means used to provide organic matter on the lighter classes of soil.

The lime status of the soil is of relatively greater importance for gooseberries than for most other fruits, and soils showing any lime deficiency should be well limed after the cultivations preceding planting. Subsequently such soils should be limed at the rate of about one ton of carbonate of lime per acre, or equivalent, every third year.

A basal dressing of about 100 lb. of phosphoric acid and 100 to 150 lb. of potash per acre should be worked into the soil by the cultivations before planting. The phosphatic manure may be either high grade slag or superphosphate and the potash should be given in sulphate of potash. Gooseberries are

especially prone to leaf-scorch and probably stand in greater need of potash fertilizers than other bush fruits. On land well prepared, no further manures should be necessary during the first year, though if development is not sufficiently vigorous an application of about 30 lb. of nitrogen per acre in readily available form should be given in early summer.

In subsequent years the bushes should receive annually about 50 lb. of phosphoric acid per acre and 100 lb. of potash in the sulphate form. These materials should be lightly worked into the soil in autumn or early spring and should be followed by about 25 lb. of nitrogen per acre in quickly available form shortly before blossoming. When the fruit is beginning to develop, another dressing of 30 to 50 lb. of quickly available nitrogen per acre should be applied.

Where farmyard manure can be given in later years it should be applied as a surface dressing in spring, following the basal phosphates and potash. In years when dung has been applied further nitrogen will generally be unnecessary, and as the bushes mature the phosphates can be reduced or omitted.

The surface soil should be frequently worked to maintain a mulch and conserve moisture; and fertilizers should always be harrowed or hoed in.

Black Currant.

Black currants require rich soil conditions, appreciably better in fact than are necessary for gooseberries. Before planting, the soil should be liberally enriched in organic matter either by previous preparation or by ploughing-in a dressing of up to 30 tons of well-rotted farmyard manure per acre in autumn. Lime and basal manures should be applied before planting out, as recommended for gooseberries, and periodical dressings of lime should be given later to prevent the development of soil acidity on soils naturally deficient in lime.

In autumn or early winter an annual dressing of about 50 lb. of phosphoric acid and 50 to 75 lb. of potash per acre should be applied, followed in early spring with 50 lb. of nitrogen. A similar dressing of quickly available nitrogen should be given later when the berries are beginning to form, unless organic nitrogenous materials have been applied earlier in the season.

Where plenty of farmyard manure is readily obtainable an

annual dressing of about 10 to 15 tons per acre should be worked into the soil in autumn or early winter. This conserves the winter and spring rainfall, and a soil mulch should also be maintained during spring and summer by frequent shallow cultivations. Where farmyard manure can be used in this manner the second nitrogenous fertilizer dressing may not be required.

If farmyard manure is unobtainable other organic materials such as shoddy, waste feeding cakes, &c., may well be used, provided they can be obtained at reasonable cost.

Red Currant.

Red currants will thrive under less fertile soil conditions than are required for the best yields with black currants, and consequently they seldom receive such liberal fertilizer treatment. Red currants respond to good soil conditions, and where farmyard manure can be spared, a good dressing should be ploughed in during the cultivations prior to planting. Red currants are generally more accommodating to soil conditions than 'blacks', and probably stand in less need of lime, but any pronounced soil acidity should be met by a dressing of lime after the land has been prepared for planting.

Red currants have perhaps less need of nitrogen than black currants, but are generally more responsive than 'blacks' to potash. For fruiting bushes, a suitable basis of manuring would be 30 lb. of phosphoric acid and 75 to 100 lb. of potash per acre in autumn and 30 lb. of nitrogen in early spring. To encourage vigorous shoot growth in the first few years, more nitrogen may be given as a later top-dressing supplying about 25 lb. per acre.

Raspberry.

The raspberry requires an open, free working soil but one that will maintain a plentiful supply of moisture during the fruiting season, since the yield very largely depends upon this factor. Given plenty of moisture, but on a soil where drainage is satisfactory, the raspberry may be cultivated under a wide rage of conditions, but atmospheric moisture appears important for the best quality fruit, and good soil drainage is absolutely essential.

Deep and thorough working of the soil before planting is necessary and every means of increasing the amount of soil organic matter should be adopted both in the previous cropping and during the cultivation prior to planting. Up to 30 tons of farmyard manure per acre, where it is available, should be ploughed in during autumn, and crops should be grown to enrich the organic content of the soil prior to planting. During the preliminary cultivations, about 50 lb. of soluble phosphoric acid and 150 lb. of potash per acre should be worked in, the potash being supplied as sulphate. In early spring the canes should receive about 50 lb. of a readily available nitrogenous manure per acre. These dressings should be given annually in subsequent years, except that the phosphates may be reduced or omitted when the plants are established.

The ground between the canes should be cultivated to a maximum depth of 3 or 4 in. in early winter and opportunity should then be made to work in the annual dressing of potash. This should be similar to that recommended previous to planting, except that on strong loams the potash can usually be reduced by half.

Where the moisture-holding capacity of the soil is deemed unsatisfactory, organic materials should be incorporated with the surface soil during the early winter cultivations. Farmyard manure may also be applied round the canes in spring, and left on the surface to conserve the soil moisture during the fruiting season. It is, however, likely to be of more benefit if applied during autumn after the new canes have ripened off, and a surface mulch maintained by frequent hoeing in spring and early summer.

Loganberry.

The loganberry should be manured generally upon the lines recommended for the raspberry, but is less particular in regard to both soil and climatic conditions. A high quality sample of fruit is less dependent upon a relatively cool and humid atmosphere during fruit development. Loganberries have to produce a large amount of new cane in addition to developing the berries on the fruiting cane, and hence require very liberal manurial treatment. Soil organic matter is important for conservation of moisture and the amounts of nitrogen, phosphoric acid, and

potash recommended for raspberries can probably be profitably increased by about half for loganberries.

Strawberry.

This berry will thrive on a wide variety of soils, but is shallow rooting and yields are largely dependent on ample supplies of soil moisture. The strawberry, however, fruits comparatively early in the season and is therefore less liable to experience droughts than the later berry fruits, and moreover it occupies the land for shorter periods. Annual applications of large amounts of organic matter may therefore be less necessary than with raspberries, but the organic content of the soil must be built up before planting. The soil should be in good heart and where the preceding cropping has not left a good reserve of humus, a dressing of up to 30 tons of dung per acre should be ploughed in before the runners are planted. It is particularly important that the young plants do not suffer from lack of moisture before they become established. On light soils in districts subject to dry weather in late spring, annual autumn dressings of well-rotted organic matter are desirable.

Although the strawberry grows satisfactorily on fairly acid soils, American experience indicates that extreme acidity, e.g. a pH of less than 5·5, should be reduced by a moderate dressing of lime after ploughing. A dressing of about 100 lb. of phosphoric acid and a similar amount of potash in the sulphate form should be applied during the cultivations before planting.

In early spring a complete mixture supplying about 30 to 50 lb. of nitrogen in quickly available form, 60 lb. of soluble phosphoric acid, and 60 lb. of potash as sulphate should be worked in between the rows. This complete dressing should be given annually each spring, or alternatively the phosphates and potash may be given in autumn and nitrogen only in spring.

Hops.

Organic matter is usually regarded as a factor of much importance in producing the best soil conditions for the cultivation of hops. It is, however, probable that too much emphasis is laid upon the value of organic fertilizers, especially in old established hop gardens that have been liberally supplied with

organic matter for many years. Apart from its physical effects on the soil, it is doubtful if organic matter is advantageous since nitrogen is not required late in the season and much in fact is then definitely undesirable since it tends to delay ripening. On most soils, however, organic matter is useful as a means of improving or regulating the moisture and aeration of the soil. For this purpose a dressing of about 15 to 20 tons of farmyard manure per acre every three years will be adequate on most hop soils. Shoddy is also used, and if obtainable at a sufficiently cheap rate it may be substituted in part for farmyard manure at the rate of 1 ton shoddy for 10 tons dung. Farmyard manure is, however, preferable if sufficient supplies are available at an economical cost. The organic manure is usually best ploughed in during autumn and early winter, though some growers still apply a portion as a late spring mulch. Where shoddy is substituted for dung it may be desirable to increase either or both of the phosphatic and potassic manures, since shoddy contains only nitrogen.

The lime content of the soil must receive careful attention for the successful cultivation of the crop, and any pronounced acidity should be corrected before planting. Thereafter a periodical application of a half ton of lime per acre or about a ton of ground carbonate per acre should be given. The lime should be worked into the surface soil in early spring before the fertilizers are applied, and the liming should be carried out every third year under most circumstances.

The subsequent manuring should consist of a basal dressing of a complete fertilizer during March and a later dressing towards the end of April or in early May of a quick acting nitrogenous fertilizer to encourage good burr formation.

The nitrogen in the basal dressing should be ammoniacal, the phosphoric acid should be highly soluble, and the potash is probably best applied as either sulphate or muriate, i.e. not in low grade potash manures. Where fairly quick acting organic nitrogen manures such as hoof and horn, meat meal, fish manure, guano, and rape dust can be obtained as cheaply as inorganic nitrogenous manures, they can be used with advantage in the early spring basal dressing. The following dressings indicate the amounts of nutrients which as a rule can be used profitably.

Rates of Application per Acre.

	Clay soils.	*Good loams.*	*Light soils.*
Hops in bearing:	lb.	lb.	lb.
Nitrogen	250–300	200–250	150–220
Phosphoric Acid	200	100	100
Potash	150	200	250
First Year:			
Nitrogen	75	50	50
Phosphoric Acid	150	100	75
Potash	50	100	100

In years when shoddy or farmyard manure is used the amount of nitrogen applied in fertilizers should be reduced by approximately a third to a half of the nitrogen supplied in the dressings of organic material. The potash may be similarly reduced when farmyard manure is applied. About half of the nitrogen supplied by fertilizers should be given in conjunction with the phosphates and potash in March and the balance of the nitrogen will be applied in a quick-acting form in two or three top-dressings. The first top-dressing will, as a rule, be given about mid-May and the final dressing towards the end of June. Each dressing should supply from 30 to 50 lb. of nitrogen per acre, the lower rate being used when the environment has produced satisfactory growth or for the more vigorous varieties. All fertilizers should be broadcast between the rows and worked into the surface soil.

INDEX